University of Alberta

Distal Ecologically-Mediated Human Health Impacts Associated with World-Wide Industries: A Case Study of the Global Farmed Atlantic Salmon Industry

by

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Abstract

Modern international trade is characterized by appropriation of global ecological capital for generating local wealth. Consequently, it is axiomatic that health impacts which might otherwise be associated with degraded local ecological conditions can be deferred and/or displaced temporally and spatially.

This study investigated specific aspects of the ecology-human health relationship using the global farmed Atlantic salmon industry (GFASI) as a case study. The research proposition was that of a causal web, providing a framework for assembling relevant information for scientific enquiry. In addition, to guide the determination of trade-offs between the ecologically-mediated health impacts of global industries and their economic consequences, an accounting framework was developed.

Ecosystems underpin the human economy and sustain human health improvements. Further research into the mechanisms by which ecologically-mediated population health impacts are offset, using the GFASI as a focus, is recommended to fill identified knowledge gaps. Refinements to the accounting framework also are proposed.

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List of Abbreviations

BC	British Columbia
BSE	Bovine Spongiform Encephalopathy
CD	Compact Disc
CDC	Centers for Disease Control and Prevention (USA)
CO_2	Carbon Dioxide
CVD	Cardiovascular Disease
DALY	Disability-Adjusted Life Year
DESA	(UN) Department of Economic and Social Affairs
DPSEEA	Driving Forces—Pressures—States—Exposures—Effects—Actions
EF	Ecological Footprint
EFA	Ecological Footprint Analysis
EI	Ecological Integrity
EIA	(US) Energy Information Administration
ENSO	El Niño/Southern Oscillation
EU	European Union
FAO	Food and Agriculture Organization (of the United Nations)
FCR	Feed Conversion Ratio
GFASI	Global Farmed Atlantic salmon Industry
GDP	Gross Domestic Product
GINI	GINI coefficient (after Corrado Gini, 1884-1965)
GHG	Greenhouse Gas
gha	Global Hectare (measurement unit in EF)
GM	Graphical Model(ing)
GNP	Gross National Product
GPI	Genuine Progress Indicator
GWA	Genuine Wealth Accounting (model)
H_A	Research Hypothesis
HCUE	Humboldt Current Upwelling Ecosystem
HDI	Human Development Index
H_0	Null Hypothesis
IAEA	International Atomic Energy Agency
IMARPE	Instituto del Mar del Perú
IMPACT	International Model for Policy Analysis of Agricultural Commodities
ISH	Index of Social Health
IUU	Illegal, Unregulated and Unreported (Fishing)
I=PAT	Impact = (Population)(Affluence)(Technology)
MEA	Millennium Ecosystem Assessment
MEME	Multiple Exposures, Multiple Effects
NCHS	National Center for Health Statistics (USA)
N	Nitrogen
NGO	Non-governmental Organization
O_2	(Atmospheric) Oxygen
O_3	Ozone
OECD	Organization for Economic Cooperation and Development
P	Phosphorus

PAHO	Pan-American Health Organization
PCB	Polychlorinated Biphenyl
PEO	Population/Exposure/Outcome
PHF	Population Health Footprint
PICO	Population/Intervention/Control/Outcomes
RCT	Randomized Controlled Trial
(P)LCA	Product Life-Cycle Analysis
PPP	Purchasing Power Parity
SEM	Structural Equation Model(ing)
SO	Southern Oscillation
SO_x	Sulphur Oxides
SSHRC	Social Sciences and Humanities Research Council (of Canada)
STIRPAT	Stochastic Impacts by Regression on Population, Affluence and Technology
TL	(Mean) Trophic Level
UK	United Kingdom
UNAIDS	The Joint United Nations Programme on HIV/AIDS
UNCLOS	United Nations Convention on the Law of the Sea
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Program
USAID	United States Agency for International Development
UV(B)	Ultraviolet (B) Radiation
WHO	World Health Organization
WRI	World Resources Institute
WWI	Worldwatch Institute

Chapter 1. Introduction

1.1. Outline of this chapter

This chapter will introduce important concepts, understandings, and themes in research involving ecological change and human health. After introductory remarks on the nature of human economic activity as a generator of ecological change and exposures, challenges for the emerging field of eco-epidemiology in a complex world are discussed. The ecosystem-economy connection is then explored in more detail, followed by consideration of ecological externalities and a brief review of attempts to value ecosystem "goods and services." The relationship between wealth, health, and levels of consumption is then discussed, and the theory and use of the Ecological Footprint (EF) as a tool for measuring the ecological demands of human enterprises is reviewed. Further discussion ensues of ecosystem goods and services and their functions, including a consideration of how compromise in these areas may influence human health. The research of Sieswerda et al (2001) into ecological change and human health (at the national level) is subsequently reviewed as a way of showing how ecologically-mediated human health impacts may be "buffered" by international trade. Finally, several tools and frameworks for investigating the impact of ecological change on human health are considered. These include the DPSEEA framework, Product Life-Cycle Analysis, the I=PAT equation, and classic epidemiological approaches.

1.2. Ecological change from global trade as a determinant of human health

The vast commercial movements of goods, inputs to goods, capital, money, services, and people between and among nations—global trade—and the forces that drive these movements rely on the development and modification of countless landscapes and ecosystems. In these locations, groups of people are exposed to specific agents, socioeconomic influences, and ecological conditions that affect their health. Canadian consumers alone spend billions of dollars each day in the global economy, directly supporting a wide array of resource extraction, manufacturing and processing, commercial and retail, service, and waste management industries. The complexity of the global economy as a dynamic generator of life circumstances globally, across time and space, coupled with both the magnitude and pace of degrading ecological life-support systems by human activity, is unprecedented in history. Epidemiological thinking is expanding to consider the public health implications of the modern world's economic activity (McMichael, 2006, 1993).

As practitioners of an applied science with an emphasis on disease prevention, epidemiologists need to be concerned with the health-related impacts of modern economic activity. The daily human practices of producing, buying, and selling goods and services are not usually considered explicitly as causes of population-wide exposures worthy of epidemiological investigation. The issues and questions raised by this new way of looking at global population health require new methods and approaches; looking only at historical exposure and outcome data cannot inform policy decisions that must consider likely future scenarios associated with complex, multi-scale ecological, economic, and socio-cultural dynamics. There is a need to estimate future changes in health risks owing to plausible scenarios of ongoing changes in these complex systems (McMichael, 2006)

1.3. Conceptual and methodological challenges for epidemiology in a complex world

Pearce and Merletti (2006) state in a discussion of complexity that:

> "…the health of a population can be viewed as a complex adaptive system. A population is not just a collection of individuals; rather, each population has its own history, culture, and socioeconomic structures, which survive despite massive global economic change while at the same time being affected and shaped by such changes."

One of the important relationships—or rather, web of relationships—in the complex adaptive systems described above is that between human beings and the ecosystems in which they participate. Because of the complex, self-regulating, and open nature of ecological systems, investigations of health-ecology relationships necessarily must deal with complex systems and the serious limitations of linear causal models that presume the consistency of internal and external system drivers over time, as well as the static nature of basic relations between system elements. According to Costanza and Wainger (1993), systems are groups of interacting, interdependent parts linked together by exchanges of energy, matter, and information. Complex systems are characterized by strong (usually nonlinear) interactions between the parts, complex feedback loops that make it difficult to distinguish cause from effect, and significant time and space lags, discontinuities, thresholds, and limits.

Pearce and Merletti (2006) state that five concepts describe complexity: self-organization, adaptation, upheavals at the edge of chaos, the unpredictability of the effects of small changes in the initial conditions, and the existence of simplicity at some levels while "chaos" exists at others. Consequently, multiple linear effects cannot simply be summed to describe the effect of the total system. In terms of the relevance of complexity to the prevention emphasis of epidemiological practice, the history of the population-ecology system becomes important, as does the anticipation of future changes in the system that may be induced by factors normally not considered in epidemiological investigations.

Ecological epidemiology, or eco-epidemiology, can be described as the subfield of epidemiology that is concerned with the evolution of human health and disease as it is affected by, and affects, ecological change. Eco-epidemiology should be distinguished from *environmental* epidemiology. The latter has always been concerned with environmental causes of disease, and with the etiological insights to be gained from studying the unequal distribution and intensity of environmental exposures and the human health implications of these exposures. Exposures of interest to environmental epidemiologists include air pollution, water pollution, and occupational exposures to physical and chemical agents (Martens, 1998). In eco-epidemiology, we attempt to look at the natural and human-influenced drivers and mediators of the ecological conditions (broadly speaking) that cause these exposures to vary over time, and attempt to model future scenarios from these evolutionary dynamics. Eco-epidemiological investigations, rather than attempting to determine causes of disease from historical exposure data, focus on projecting ecological trends (and measurable and influential human trends) into the future in order to anticipate the population health implications of historical, present, and future changes to ecological conditions at various spatial scales. It should be recognized, however, that much of the knowledge about different parts of a complex eco-health model will still come from conventional environmental epidemiological research, and that the consideration of complex systems requires some knowledge of the parts. This knowledge is still obtained largely through research that seeks to improve understandings of disease causation via conventional epidemiology (see Table 1.).

Reckoning with the population health implications of ecological upheavals, where the equilibrium point(s) of an ecosystem (or of multiple ecosystems) change radically and perhaps irreversibly, is also one of the challenges of eco-epidemiology. Anticipating the human health implications of global climate change, for example, requires an eco-epidemiological perspective: the effects of global climate change will affect human health through multiple mechanisms acting on multiple sub-populations of humans over multiple temporal and spatial scales. In addition, major change to the climate system could initiate negative and positive feedback loops which affect water, wind, and nutrient cycles and events in unpredictable and dramatic ways, with potentially catastrophic changes to the ecological systems that currently support the global economic system that billions rely on to provide food, water, and other basic-needs goods, and (for those who can afford them) a vast array of non-essential goods.

It should be noted that as human conditions (such as agricultural and industrial activities, and residential patterns) change in response to the impacts of climate change, the rate of that climate change is also likely to vary. The relationship between human activity and climatic conditions is dynamic, and, as such, humans have influence on climate change both by the preventive actions that they take and by the ways in which they react to changes that have been demonstrated already. Thus, caution is warranted in the interpretation both of the direction and nature of causation that is suggested by analyses of variables such as the atmospheric concentration of CO_2.

In sum, the major differences between conventional environmental epidemiology and eco-epidemiology have to do with: (1) spatial scale of exposures and outcomes; (2) temporal scale of exposures and outcomes; and (3) level of complexity (Martens, 1998). Table 1. below, adapted from Martens (1998), shows the major conceptual differences between conventional and eco-epidemiological frameworks. Each of these features is relevant to any exploration of the human health impacts associated with a global industry that includes, by definition: (1) significant distances between consumers and producers and/or significant delays in the realization of ecological and related health impacts; and/or (2) similar schisms between consumers and producers and the various providers of the inputs to production. Space precludes a thorough discussion here of the features of eco-epidemiology that distinguish it from conventional epidemiology, but one especially noteworthy feature is the attention to long time horizons. Long-term natural cycles, evident in some parameters of the ecosphere such as atmospheric CO_2 concentration, require careful consideration from an applied epidemiological perspective. This is so that anthropogenic contributions to large-scale ecologically-mediated exposures (such as global warming) are neither under- nor over-estimated, and so that the best mix of preventive and adaptive measures can be taken.

Table 1. Main differences between conventional and eco-epidemiology

Conventional Epidemiology	Eco-epidemiology
Toxicologic	Ecologic
Estimation of risk from past realities	Assessment of future health risks
Short time horizon	Long time horizon
Estimation of more local risks	Estimation of global and regional risks
Statistical models	Mathematical models
Static cause-and-effect	System-dynamic, nonlinear models
Reductionistic approach	Systems-based or holistic approach

1.4. The ecosystem-economy connection

An *ecosystem* is a dynamic set of living organisms in interaction with each other and with the abiotic elements of the environment in which they live (Natural Resources Canada, 2007). The *economy* is that set of activities and relationships by which humans acquire, process, and allocate the material (and energetic) necessities and luxuries of life (Rees, 2000). As such, economic activity is inherently ecological activity, because it involves the movement and transformation of non-living as well as living elements, and because it affects the relationships that exist between these elements. As most of humanity has known for millennia, the predictable bioproductivity of terrestrial and marine ecosystems, the ready availability of nature's renewable and non-renewable resources, and the capacity of the surrounding environment to assimilate the waste and by-products of human living make possible all daily human economic enterprises—from gathering wild foods to manufacturing computer chips and automobiles. All economic systems, historical and contemporary, depend on a healthy, productive, and resilient web of terrestrial and marine ecosystems, including the atmosphere.

When ecological conditions deteriorate catastrophically, dramatic impacts on human health can result; this truth is brought home through the consequences of flooding in Bangladesh, drought in sub-Saharan Africa, and the elimination of ecosystem "goods and services" from forests in Haiti or Brazil, with resulting impoverishment of rural populations. Incremental ecological change may have population health effects as well; for example, the spread of some vector- or rodent-borne diseases such as malaria and dengue into new regions is projected as changing heat, humidity, and human disruption of the landscape create ecological conditions beneficial to the disease-carrying organisms (McMichael et al, 2001). Still, scientific research is needed to help us quantify the extent of these kinds of impacts, determine where thresholds exist that are less than catastrophic (Soskolne and Broemling, 2002), and identify some features of our economic activity that either directly cause ecological degradation or which exacerbate the damage caused by natural stressors such as tsunamis and earthquakes.

Ecology-economy dynamics exist at many levels. The global level is one level, and global trade is a key dynamic at that level. As one important part of the total human economy, global trade means the commercial movement of goods, inputs to goods, capital, money, services, information, and people among nations. Since all the matter and the sources of energy used to transform that matter ultimately derive from the natural environment (the ecosphere plus the constant influx of solar energy), maintaining the flow of resources through productive enterprises requires healthy ecosystems that are resilient in the face of external pressures or insults—i.e., that have the capacity to continue to provide that regular flow of goods and services. This capacity, or resilience, is sometimes called ecological integrity. Where that integrity has been challenged or destroyed, or where the resources required for the production of goods to be marketed are exploited more quickly than their ability to regenerate, the short- and/or medium-, and/or long-term sustainability of the dependent wealth-generating enterprises are imperiled. And because new ecological equilibrium points may result, the possibility of future wealth-generating enterprises in that region likely will be compromised. This is the meaning of *non*-sustainable development, development which reduces the ability of future generations to meet their needs. The Millennium Ecosystem Assessment (MEA) affirms this by stressing that any progress achieved in addressing goals of improved health and environmental protection is unlikely to be sustained if ecosystem services (see Table 2.) around the world continue to be lost (MEA, 2005).

Long-distance (especially international) trade complicates the idea of sustainable economic enterprises. So long as long-distance trade is possible and economical, wealth-generating activities can continue even when the "goods and services" from local or regional ecosystems (i.e., those within the producing nation) can no longer support them. Productive activities, formerly domestic in nature, can be moved and based elsewhere (such as a country on the other side of the planet), and the money wealth and/or goods generated by those productive activities can be imported. Consequently, the local or regional ecological support base in the importing country is no longer required to play a foundational support function in the production activity itself.

The "ecological capital" or "natural capital" of other nations can be appropriated or imported, either in direct forms such as timber, oil, and agricultural goods, which provide raw materials for domestic secondary or tertiary production or are consumed with little processing, or indirectly through the embodied ecological capital and energy in processed or manufactured goods from other nations. This allows the importing country to defer in time and/or displace in space the ecological consequences of its production and consumption activities, and thus it allows firms and individuals in the importing country to dissociate the generation of monetary wealth from the integrity of the ecological foundations of that wealth. With domestic production more dependent on a domestic resource base, ecological consequences would provide negative feedback to curtail the production and consumption activities or to force the development of ecologically sustainable technologies. Because of extensive international trade and foreign-owned capital, the global relationship between human health and ecological integrity is obscured; trade-savvy countries can offset any ecologically negative effects of consumption domestically by importing carrying capacity (or exporting polluting industries and wastes) to other countries via the global market. In this thesis, we will sometimes refer to this intentional or unintentional deferment or displacement of consequences as "buffering."

Some environmental economists argue that further economic development can solve rather than exacerbate problems of ecological degradation from production enterprises (Grossman and Krueger, 1995). Again, however, the global nature of trade means that the wealth and resources deemed necessary for turning the attention of civil society towards environmental quality concerns can be located at a distance from, and in a different political jurisdiction than the damaging productive enterprises themselves.

Global trade is, of course, not the only means by which the potentially corrective ecological feedback from over-consumption might be attenuated or deferred; the nations of the world vary widely in their population densities, endowments of natural resources, and political and social capacities to respond to ecological change. This thesis will only peripherally treat these other means. Mainly, the focus of this thesis is on the way that global trade (for example, the import of raw materials from other countries) serves to displace some ecological impacts to locations distant from the points of production and consumption.

1.5. Externalities and eco-epidemiology

Because ecological reality consists of complex relationships between vast numbers and types of biotic and abiotic entities, the ecological, social, and economic problem of externalities is especially relevant to public health investigations that involve an assessment of the links between ecology and economy and human health. The presence of externalities means that much of the official trade, production, and associated data derived from standard industrial and commercial accounting are incomplete. They can fail to mention—let alone attempt to quantify—important human health risk factors that exist partly or entirely because of an industry's operation. In the same way, health benefits of a certain industry may be missed, again because there is an incomplete accounting of the industry's impacts on the natural and social worlds.

By conventional definition, an externality exists when an economic actor produces an economic cost but does not fully pay that cost (negative externality), or when an economic actor produces an economic benefit but does not fully reap the reward from that benefit (positive externality) (Goodwin et al, 2006). The classic negative environmental externality is air pollution; an industry produces plastic shovels, for example, but the consumers who benefit from the production of those shovels are not the only ones who are affected in some way by their production. Involuntarily, many other people are affected by the toxic gases which are emitted during the production of the shovels. These individuals did not "purchase" the contaminated air that they are breathing into their lungs, nor did the polluter pay the social costs of the consequences. In this case, those individuals also do not desire to breathe that toxic air. It is also possible for a third party to *benefit* involuntarily from a transaction that is theoretically supposed to take place between two interested parties who are aware of (and bear) all the costs and benefits of that transaction. Classic economic theory holds that there will be an overproduction of goods that create negative externalities, because the costs of these unplanned and unaccounted harms are never paid by the producer; in contrast, it is assumed that goods for which production produces positive externalities will be underproduced, because the producer is in effect paying to produce something that can be consumed for free and for which it will receive no remuneration for its efforts.

There are at least two important reasons why the price of goods may not reflect the costs and benefits associated with their production, whether these costs and benefits are understood in ecological, social, or economic terms: (1) the externalities are not known; and (2) there is no adequate means of valuing the externalities and thus internalizing them so that their existence is reflected in price. Dealing with the former problem requires in-depth knowledge of the ecological, economic, and socio-cultural web in which "transactions" actually take place, and it requires accurate data; addressing the latter problem means developing a method of measuring the impact of externalities in dollar terms and then incorporating those monetary costs and benefits into the price of the good. One of the reasons that the global "free" market has failed to radically reflect the price of ecological integrity and sustainability is because specific environmental harms are difficult to value. Competitive advantage also may be gained by producers if they can lower production costs and thus sell their products at lower prices, potentially gaining greater market share. Thus, there is a private incentive to externalize any costs of production (such as some ecological costs) which are not identified or not valued in the economy. System-wide harms to complex ecological systems, including those catalyzed by global warming, present an even more vexing challenge.

Our primary concern in this study, as described in Chapter 3, is with the impacts on the health of a particular human population of selected externalized ecosystem changes caused by a particular global industry. Without attempting to establish links between the loss of the provisioning features of global ecosystems and specific human health impacts, Costanza et al (1997) attempted to calculate the total value of all the world's ecosystem services and natural capital, based largely on multiple prior studies which had been conducted in an attempt to value discrete ecosystem services and natural resources. In total, as these researchers suggest, the value of ecosystem services and natural capital is effectively infinite, since all other kinds of capital (e.g., human capital, manufactured capital) used to "produce" human welfare are wholly dependent on the provisioning and regulating functions of ecosystem services, as well as on the actual physical reservoir of materials and energy that natural capital provides. However, Costanza et al (1997) assert that it is meaningful to ask how changes in the quantity or quality of various types of ecosystem services and natural capital may have an impact on human welfare; in part, this is simply the question of the marginal costs and benefits of ecological externalities. Human welfare is more complex than monetary wealth or the absence of particular diseases or health risks, however, and many of these dimensions are not easily measured or not measurable directly. In addition, individual valuation of ecosystem services or natural capital is likely to consist of poorly informed estimates. This complicates the process of internalizing the currently externalized costs (and benefits—for example, when an ecosystem change reduces the population of a disease vector) associated with economic activities that impact the global environment—especially when these costs and benefits are associated with ecological changes at various spatial and temporal scales. Consequently, very little research has been conducted to clarify the relationships between the loss of specific types of ecosystem services and natural capital and specific human health outcomes. Chiesura and de Groot (2002) consider natural capital from a socio-cultural perspective, and discuss the "information" or nonphysical functions of ecological services (e.g., recreation, amenity, and education) and suggest that these functions provide socio-economic benefits even though they are immaterial and often intangible. These functions too are almost always externalized in economic activity and price-setting, except when they are deliberately marketed (as in eco-tourism, for example). Determining their relationship to specific human health conditions may be even more difficult than for ecosystem services responsible for the production or circulation of measurable quantities of physical material (such as water).

1.6. Wealth, health and consumption at several scales

At least in the short-term, population health in contemporary societies that are well-connected to resources by international trade, and which have advanced technology that can reduce noxious air, water, and soil pollutants from combustion activities, appears to depend little on the ecological integrity of those societies' domestic environs. However, a large body of research has established that gross monetary or material wealth (which is ultimately derived from a healthy ecology), whether measured at the country, community, or individual level, is strongly and positively correlated with many basic measures of population health. Wealth, whether private or public, enables the development and/or purchase of public health measures, adequate housing, health care, cleaner fuels, and a varied and secure food supply. Wealthier nations can provide clean and accessible water, and can support universal primary education and institutions of higher learning; wealthier individuals can live in "safer" neighbourhoods, afford vehicles with better safety features, and eat more nutritious foods, among other things. Although wealth is often identified exclusively with money, it can be defined more comprehensively as the conditions for well-being, including the necessary conditions for good population and individual health (Anielski, 2001). The specific elements in this more useful conceptualization are lost in a singular focus on monetary wealth.

Income inequality also is related to health. As work by Wilkinson (1996) and others has led Peña and Bacallao (2002) to point out, inequality in the distribution of money and other resources within societies, and the impact of this inequality on health, is not a methodological artifact. Rather, it has been established by indisputable scientific evidence. While the mechanisms by which income and resource inequality within societies (and potentially between nations) affect health are not the primary focus of this study, it is important to remember that changes in the distribution of wealth, in addition to changes in the gross level of wealth, will have health impacts. World-wide or global industries, such as the farmed Atlantic salmon industry described in the present study, impact ecological health at multiple scales; they also impact both the distribution and the amount of monetary wealth in society.

The consumption and production behaviours of every one of us, as individuals and as parts of collectives such as businesses, amount to the global trade of billions of dollars of tractable goods and services on a daily basis. Transactions for which there is no accounting (i.e., those in informal household economies or the "black" market) also contribute substantially to the volume and value of goods and services that move within and between nations. The world economy has grown five-fold within the last several decades (Rees, 2000). The formally stagnant economies of China and of many other countries are growing rapidly as export earnings increase, as industrial capacity enlarges, and as goods (and whole lifestyles) made popular in western nations are exported to the developing world, stimulating demand. By 2010, China will likely become the world's largest economy, supplanting the United States in the place it has maintained for decades (WTO, 2003). By mid-century, China will also use more oil than the United States, and, by extension (if radically new technologies are not adopted), will produce the most climate-changing greenhouse gases. Air pollution and regional ecological problems also abound: China already has 20 of the world's 30 most polluted cities (World Bank Group, 2007). Other countries are also ramping up their economies, consuming resources, and impacting the global ecology profoundly; India's exports of merchandise, for example, continue to grow at an annual rate of 20% or more (DESA/UNCTAD, 2006). Still, the ecological demands made by the wealthiest countries in the world are highly disproportional from a *per capita* perspective; for example, Canadians consume almost four times the meat and six times the paper of the Thai, and 12 times the meat and more than 150 times the paper products of the Nigerians (World Resources Institute, 2006). A discussion of all of the reasons for these discrepancies is beyond the scope of this study. However, the contrast shows the wide range among nations in resource consumption, which, along with population size/growth rate and technological differences, suggest the complexity of global-scale problems that require the cooperation of all nations. The differences between persons and nations in their contribution to humankind's apparent overconsumption of global biocapacity also indicate the need for context-specific interventions that reflect the nature of the impact that any one entity has on the ecosphere.

1.7. Ecological Footprint Analysis (EFA) and eco-epidemiology

The ultimate concern in the ecology-human health relationship is that the total human population has grown so large and consumes so much that collectively we are demanding more goods and services from the ecosphere than the ecosphere can sustainably provide. In ecological terms, this claim holds that our total population, consuming at the current average rate, is greater than can be supported by the global network of ecosystems that supplies the demanded resources and waste assimilation capacity. The situation is complicated and dynamic because, as noted earlier, humans can trade extensively, develop new technologies and efficiencies in production, and can, at least theoretically, control the amount that they consume as individuals and societies, as well as the rate at which they reproduce.

However, at present we are showing no signs of making substantial changes to the rate at which we consume resources, change or degrade ecosystems, and emit greenhouse gases (WWI, 2006). Our global Ecological Footprint (EF) shows that we are living beyond our means; the rate at which human beings are exploiting the Earth's biophysical output is currently unsustainable (Wackernagel et al, 1999). As Wackernagel and Yount (2000) state:

> The current global level of resource consumption and waste generation, to be sustainable, would require a biotically productive area greater than that of the biosphere. Furthermore, if all countries were to achieve the level of consumption characteristic of the OECD countries [namely, countries such as the USA, Canada, the UK, and Australia], the area required would be at least three times that which is available.

Conduct of Ecological Footprint Analysis (EFA) can yield a summary measure of the demand placed on bioproductive land and water areas by a consuming unit such as a household or nation. (For a simple description of the process of EFA, see Appendix 1.). The *global* EF provides a gross measure of whether, given the continuation of prevailing technological, economic, and political arrangements, humankind is exploiting Earth's ecological capital at an unsustainable rate. If so, the ecological dynamics that render the fundamental material and energetic resources on which we depend will eventually be altered so substantially that they will not provide the necessary support for human life. Expressed in terms of an inequality:

Global EF of humanity > Total global hectares of biocapacity = unsustainability or ecological overshoot

The general form of this equation can be applied to any particular ecosystem upon which a human population depends for meeting basic needs: water, food (or, conditions conducive to producing food), fiber for clothing, materials suitable for fuel and construction, and ecosystem "services" (such as carbon sinks) for assimilating wastes. Historical examples exist of cultural collapse largely attributable to the exhaustion of regional/local scale ecosystem goods and services in the absence of the buffering effects of international trade. The Mayan civilization in the 8th and 9th centuries CE and the society on Easter Island in the 1700s are two such controversial examples (Diamond, 2005).

There are dramatic regional and country-level differences in consumption and thus in the size of the EF between different nations and individuals within those nations. Estimates of Earth's bioproductive and waste assimilation capacity indicate that on a *per capita* basis there are approximately 1.8 global hectares (gha) of biocapacity available for a world population in 2003 of approximately 6.3 billion (World Wide Fund for Nature, 2006; United Nations, 2005). The average *per capita* EF in 2003 was approximately 2.23 gha (World Wide Fund for Nature, 2006), indicating roughly a 22% overshoot of Earth's ecological capacity to support humans at then current consumption levels. Looking at averages masks important within-country and between-country differences, however. For example, the *per capita* EF of the United States is about 9.6 gha, while Canadians live a lifestyle that requires 7.6 gha/person of biophysically productive land and water area. The average resident of The Netherlands requires 4.4 gha. At the very low end of the distribution are materially poor or strife-ridden countries such as Haiti (approximately 0.6 gha/person), Somalia and Bangladesh (0.4 and 0.5 gha/person, respectively) and Afghanistan (0.1 gha/person) (World Wide Fund for Nature, 2006). Different types of human settlements, understood as consuming-units within nations, also vary widely in the intensity of their resource use. Modern cities, in contrast to sparsely populated rural areas with little infrastructure, are especially unsustainable forms of human settlement.

Vancouver, for example, occupies approximately 11,400 hectares of land area, but requires nearly two million global hectares to maintain the material and energy metabolism of its people, its infrastructure, and its institutions (Rees, 1996). The actual ecological areas that sustain Vancouver are, of course, located all over the planet.

As with different types of human settlements, different human economic activities also vary in their intensity of resource consumption, and thus in the sizes of their EFs. For example, per kilogram of protein, the production of beef requires nearly an order of magnitude more energy than the production of a kilogram of turkey or wild-caught salmon (Tyedmers, 2000).

For epidemiologists concerned with the human health impacts of ecological change or degradation, the inequitable distribution of the sources of negative impacts on the ecosphere, and thus on the health-related factors that a perturbed ecosphere influences, raises ethical questions, etiological questions, and questions about the most effective kinds of interventions for preventing future morbidity and mortality related to changes in ecological health. EFA can contribute valuable information to help answer these questions. For example, concurrent work being done by Kissinger and Rees (unpublished, 2007) to disaggregate EFs for particular societies or particular economic goods, will provide even more pertinent information for eco-epidemiological investigations that focus on the ecologically-mediated health impacts of production/consumption patterns in populations.

Consumption itself can be defined in economic terms as the act of purchasing or procuring a good or service, or in physical terms as the act of appropriating and using energy and/or materials to build, maintain or expand public or private infrastructure, to meet basic needs, or to sustain the demands of particular lifestyle preferences or desires. By both definitions, consumption demands production, and production supplies consumption such that the two are intimately related. Consumption and production are really two sides of the same coin, and for many modern products and services, they implicate a complex web of activities and enterprises. In the global human EF, the production and the consumption "footprints" are identical. Wackernagel and Yount (2000) put it this way:

> …the footprint of production is not an additional footprint, but rather an impact analysis that organizes the environmental impacts from the production rather than the consumption perspective. For the globe (or humanity) as a whole, the consumption footprint will be identical to the production footprint since there is no trade with other planets and, therefore, essentially everything produced on the planet will eventually be consumed on the planet (what is not consumed can be considered to be waste associated with the consumed goods). For any subsection such as a nation, a region or a household, however, the consumption and the production footprint do not have to balance out.

This is an important point. It shows that consumption and production (and the wastes associated with them) cannot be separated ultimately, but rather only when frames of reference smaller than the planet are used. The main implication of this for the sustainability of population health is that the ecological concept of carrying capacity applies to human beings as it does to other organisms, even though modern trade evidently allows specific concentrations of human beings to live beyond the carrying capacities of their regional ecological bases for varying lengths of time.

As with their consumption of specific resources and with their ecological footprints, nations are also unequal in their contributions to climate change processes, such as the global warming accelerated by carbon dioxide emissions from human industry. Canada, for example, accounts for less than 0.5% of the world population but contributes about 2% of the carbon dioxide from human sources (UCSUA, 2006). Unequal contributions in this particular realm pose a unique challenge to policy-making and to the attribution of population health consequences of climate change, because CO_2 emissions contribute to the atmospheric concentration of CO_2 regardless of where on the planet the gas is actually emitted.

Numerous scientific papers and scholarly and popular books published by Rees and/or Wackernagel (e.g., Rees and Wackernagel, 1994; Wackernagel and Rees, 1996; Rees, 1996) outline the theory and application of Ecological Footprint analysis (EFA). Critiques and reviews of the method, as well as discussions of methodological developments in EFA, have helped hone the practice of EFA in recent years (for example, see van den Bergh and Verbruggen, 1999; Levett, 1998; Lenzen and Murray, 2003; and Lenzen and Murray, 2001). Regular concerns and items of debate include the appropriateness of using the land and water area required for carbon assimilation as a measure of the EF of a given level of hydrocarbon fuel combustion, and the appropriate depth of the analysis with respect to the embodied energy of the inputs required to produce the basic energetic and material "goods" (such as oil or wheat) that are footprinted in the general analysis. This study does not attempt to critique or substantially alter the EFA method when it is applied to the global farmed Atlantic salmon industry (see Chapter 4). Instead, it employs the technique mainly as a way of suggesting the magnitude and the types of human health impacts associated with economic enterprises which, because they are ecologically unsustainable in global terms, contribute to an ecologically unsustainable global economy. No single indicator can capture all the dimensions of the concept that it aims to measure, especially in contexts of enormous complexity such as the biosphere. The EF is no exception to this criticism. Importantly, because EFA involves estimating impacts based on the world-average productivity of several basic ecosystem types, it does not account for the relative differences in the health of the specific ecosystems from which resources are actually being appropriated. EFA also does not address potentially important qualitative issues such as the toxification or sterilization of key ecosystem elements such as soil. Finally, because of the measurement problems associated with many dimensions of EFA, estimates are usually biased on the conservative side, suggesting that the bioproductive areas required by the analyzed entities are probably understated.

Since the early years of its development and popularization in the 1990s, EFA has been extended and adapted to a range of scales, types of activities, and types of communities or institutions (for example, see Germain, 2001; Tyedmers, 2000; Bicknell et al, 1997;

and Wackernagel and Rees, 1996). Most relevant to the current study, Tyedmers (2000) conducted an EF and energy throughput analysis of both the capture and cultivated salmon industries in British Columbia. Tyedmers' original work forms the basis for the gross EF estimate that is made in the present research on the global farmed Atlantic salmon industry.

Basic EFA ties in with eco-epidemiology primarily by clarifying the magnitude of the demand that human activity places on the ecosphere (e.g., the extent of global ecological overshoot, based on the productivity and assimilative capacity of the world's ecosystems), and by estimating the ecological metabolism of particular enterprises, institutions, or communities as compared to others. It thus defines basic ecological parameters, which then may be investigated for their relationship to human health. The former function—characterizing the gross mismatch between consumption and bioproductivity—is served by an aggregate EF. The latter function requires the further identification of the actual geographic locations of the ecosystems from which the material and energy resources are being drawn—i.e., a disaggregation of the EF. This would help in the estimation of the full range of public health impacts of the EF of the entity being analyzed.

Because it bears on the total EF of an industry as well as its specific regional/local scale ecological impacts, the illegal, "black market," and otherwise externalized and unaccounted aspects need to be addressed when assessing the ecologically-mediated human health impacts caused by specific industries. For example, hazardous wastes often move internationally through legal and illegal trade arrangements, as countries stand to make quick money by accepting wastes which may be costly to dispose of in the countries which have produced them (Soskolne, 2001).

1.8. Ecosystem services and eco-epidemiology

EFA, without disaggregation, and including the qualifications noted above, is a useful tool for measuring the gross ecological sustainability of a community, institution, or enterprise. The specific consumption data used for the EFA can also suggest where in the world to look for the associated local or regional ecological impacts of the analyzed entity, and further ecological analysis of those locales and regions can reveal the extent and the quality of the ecological impact in those areas. To begin to make connections between ecological impacts and human population health on all sub-global scales, however, we need to know how various types of changes to ecosystem structure and function (i.e., the provisioning of ecosystem "services") increases (or diminishes) health risks to populations of interest. These kinds of investigations do not currently fall within the sphere of EFA, but they do suggest the utility of investigative frameworks such as the DPSEEA approach used by the World Health Organization and discussed in section 1.11.1.

The phenomenon of "buffering" further complicates the process of specifying health risks that have clear ecological antecedent causes. In the case of natural disasters, such as from earthquake-caused tsunamis, many of the short-term health impacts and longer-term health risks are more readily apparent, and the operative buffering mechanisms are evident in the breach. The non-immediate, ecologically-mediated human health consequences of global industries are likely much more difficult to pinpoint.

Economic variables are likely to play a much more important role in mediating risks. For example, a tsunami might destroy a subsistence fisherman's boat and gear, and thereby (assuming no immediate aid from elsewhere) directly reduce the food supply of those who depend on that fisherman's production. By contrast, a change in the mean Trophic Level (TL) of the fish catch of a commercial fishery could ultimately lead to the total elimination of all desired food fish or reduction fish species, and radical changes in the ecosystem that used to support the production of these fish. However, because the person working for the commercial fishery does not rely directly on the productivity of the relevant marine ecosystem for their sustenance (and thus for their nutritional health), but rather depends on earning cash to spend in the international food market, economic variables at several scales mediate the impact of the negative ecological event or process. The personal/familial is one of these scales, but larger scales are also relevant. For example, a government without a dependable and adequate income from the tax base cannot maintain public health infrastructure.

Ecosystems cannot easily be broken down into discrete components so that each component—such as a species or a regular cycling of water—can be analyzed as a human health risk factor independent of other components. However, categorizing the various human health benefits of particular defined types of ecosystem services, and assessing and predicting the harms to human health should those services be compromised or eliminated entirely, provides a way into what is a complex multiple exposures/multiple effects ("MEME") situation. Human beings depend on the diverse ecosystems on Earth for a wide variety of essential life-supporting materials and services such as the protection of pollination pathways and the maintenance of chemical cycling processes. One way to determine the types and distribution of human health impacts expected to result from human or non-human impacts on specific ecosystems, such as may result from an industry like the GFASI, is to first identify the types of functions that ecosystems serve in human life, and then to predict the impacts on human life when one or more of those services is compromised or lost. This strategy will oversimplify matters, because ecosystem services are highly interdependent and non-discrete; the loss of an ecosystem's capacity to provide one type of service does not leave the capacity to provide other services unchanged. Additionally, the human-ecological relationship is dynamic. The relationship between local, regional, or global ecological conditions and human health is influenced by changes in the rate at which humans consume energy and materials, the rate at which they reproduce (population increase), and the rate at which efficient and effective technologies are adopted that can buffer ecologically-mediated health risks through the substitution of functionally equivalent human-made capital for natural capital. Further, humans are an integral part of the ecosystems that they study and to which they assign value.

In the past decade or two, numerous researchers have investigated the particular benefits that ecosystems provide to humans. De Groot et al (2002) note that ecosystem goods and services are often classified differently by different authors, and that data on these goods and services often appear at scales of analysis which are incompatible. Table 2. below is a slightly expanded version of the list of 17 ecosystem services and functions as described by Costanza et al (1997). Possible human health impacts in the table below are mainly drawn or inferred from: Epstein, 2005; McMichael, 2001 and 1993; and Confalonieri, 2000. Probabilities of the possible health impacts noted in the table are not estimated; impacts are suggested only as reasonable consequences or because of historical precedent.

Table 2. Ecosystem services and potential human health impacts at different spatial and temporal scales

Ecosystem Service	**Ecosystem function**	**Examples**	**Possible short-term human health impacts (examples)**	**Possible medium-term and long-term human health impacts (examples)**
1. Gas regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance, O_3 for UVB protection, and SO_x levels	Acute respiratory conditions	Skin cancer, regional food shortages through destruction of primary marine and terrestrial producer organisms and/or disruption of nutrient cycles
2. Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels	Greenhouse gas regulation	Direct heat-related morbidity and mortality	Morbidity and mortality from chronic extreme weather events; flooding, drought, changes in distribution of disease vectors
3. Disturbance regulation	Capacitance, damping, and integrity of ecosystem response to environmental fluctuations	Flood and mudslide control	Morbidity and mortality from flood or mudslide damage	Morbidity and mortality from increased prevalence of vector-borne diseases and poverty associated with destruction of soil quality and resources
4. Water regulation	Regulations of hydrological flows	Provisioning of water for agricultural, industrial, or transportation processes	Food shortages and related morbidity and mortality	Food shortages and related morbidity and mortality

Ecosystem Service	**Ecosystem function**	**Examples**	**Possible short-term human health impacts (examples)**	**Possible medium-term and long-term human health impacts (examples)**
5 Water supply	Storage and retention of water	Provisioning of water by watersheds, reservoirs and aquifers	Water shortages and related morbidity and mortality	Water shortages and related morbidity and mortality
6. Erosion control and sediment formation	Retention of soil within an ecosystem	Prevention of soil loss by wind and runoff	Food shortages (reduced crop yields); increase in vector-borne diseases associated with increased vector populations	Food shortages and related morbidity and mortality owing to reduced ability to produce crops
7. Soil formation	Soil formation processes	Weathering of rock and the accumulation of organic material	Food shortages and related morbidity and mortality owing to reduced ability to produce crops	Food shortages and related morbidity and mortality owing to reduced ability to produce crops
8. Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients	Nitrogen fixation, N, P and other elemental or nutrient cycles	Uncertain	Uncertain
9. Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds	Waste treatment, pollution control, detoxification	Increased morbidity and mortality from increased human contact with infectious and parasitic organisms	Increased morbidity and mortality from increased contact with infectious and parasitic organisms
10. Pollination	Movement of floral gametes	Provisioning of pollinators for the reproduction of plant populations	Uncertain	Morbidity and mortality from reduced variety and efficacy of medicines derived from naturally occuring plant species; morbidity and mortality from reduced availability of food as a result of dependence on a small variety of food species

Ecosystem Service	**Ecosystem function**	**Examples**	**Possible short-term human health impacts (examples)**	**Possible medium-term and long-term human health impacts (examples)**
11. Biological control	Trophic-dynamic regulations of populations	Keystone predator control of prey species, reduction of herbivory by top predators	Increased morbidity and mortality from vector-borne diseases (especially zoonoses) owing to uncontrolled expansion of some vector populations	Increased morbidity and mortality from vector-borne diseases (especially zoonoses) owing to uncontrolled expansion of some vector populations
12. Refugia	Habitat for resident and transient populations	Regional habitats for locally harvested species	Uncertain	Possible morbidity and mortality from long-term diminished capacity for vector control and food production
13. Food production	That portion of gross primary production extractable as food	Production of fish, game, crops, nuts/fruits by various means	Morbidity and mortality associated with food shortages and/or reduction in food quality	Morbidity and mortality associated with food shortages and/or reduction in food quality
14. Raw materials	That portion of gross primary production extractable as raw materials	Production of lumber, fuel, minerals, or fodder	Morbidity and mortality associated with inadequate shelter and public health infrastructure; morbidity and mortality associated with reductions in food production capacity	Morbidity and mortality associated with inadequate shelter and public health infrastructure; morbidity and mortality associated with reductions in food production capacity
15. Genetic resources	Sources of unique biological materials and products	Medicines, genes for resistance to plant pathogens and crop pests	Uncertain	Increased all-cause and disease-specific mortality and increased severity of morbid conditions as limits are placed on discovery of new or more efficacious medicines derived from wild plant species
16. Recreation	Providing opportunity for recreational opportunities	Eco-tourism, sport fishing, and other outdoor pursuits	Increased stress; impacts on total well-being	Uncertain

Ecosystem Service	Ecosystem function	Examples	Possible short-term human health impacts (examples)	Possible medium-term and long-term human health impacts (examples)
17. Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, educational, and spiritual values of ecosystems	Impacts on total well-being	Uncertain

Human activities, such as the production and consumption activities of the global economy, can affect any number of the ecosystem services and functions outlined in Table 2. For example, the degradation and destruction of mangrove ecosystems in Thailand for shrimp aquaculture has compromised the ability of these ecosystems to buffer coastal areas from the onslaught of tsunami waves (FAO, 2005). Consequently, water regulation and erosion control (among other ecosystem functions and services) are affected. On land, clearing the rainforests of the Amazon for timber, mineral extraction, or for the production of subsistence crops threatens refugia and genetic resource provision ecosystem functions (Fearnside, 1999).

The degradation or loss of ecosystem services such as those noted in Table 2. will impact human health on a range of temporal and spatial scales, via direct and indirect pathways (McMichael, 1993). Both the temporal and spatial distributions of impacts depend in part on the affected population's capacity to buffer itself from those health risks which are determined by local or regional ecological conditions.

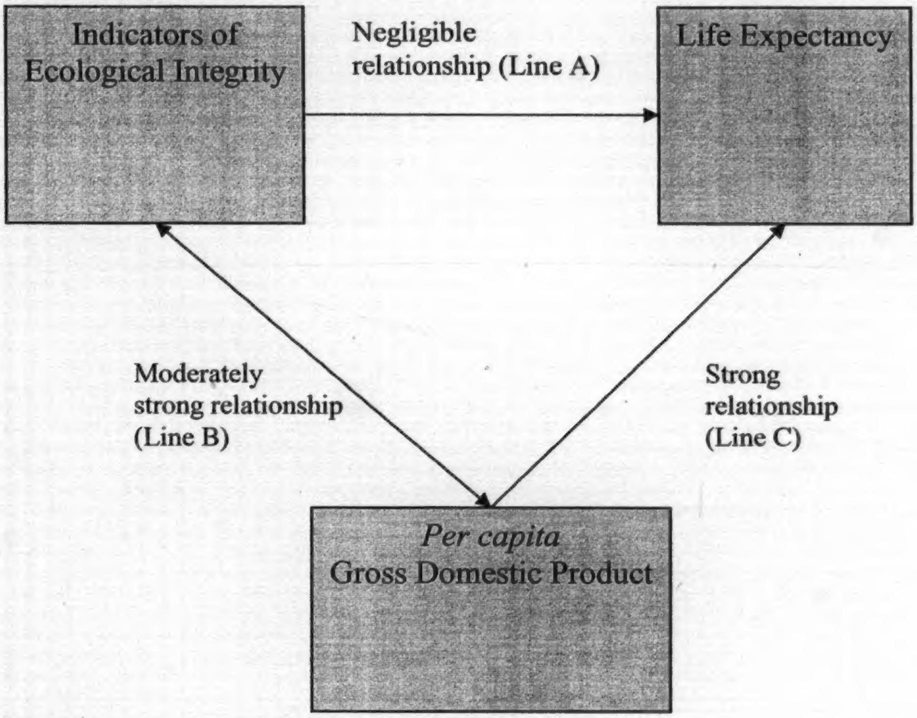
1.9. Buffering human populations from ecologically-mediated health risks

Human communities constantly attempt to buffer themselves from ecologically-mediated health risks. The development of irrigated and fertilizer-dependent agriculture for food security and the installation of dams, dikes, and levees to buffer the effects of flooding are two examples. However, contemporary global trade arrangements make a vastly more complex suite of buffering mechanisms possible, and the spatial disconnect between consumption and production activities, and thus between the location of the health benefits derived from the use of a good and the location (or time) of the ecological harms incurred in its production, is commonplace in the global economy.

The strong correlation at the individual country level of EF, Gross Domestic Product (GDP), and basic population health markers such as longevity, infant mortality, and incidence of low birth weight in live newborns (Sieswerda et al, 2001; World Bank, 2002), suggests that population health in one country (i.e., the consuming country) may be improving at the expense of ecological integrity and/or population health in another country (i.e., the producing country). This amounts to a "buffering" of health risks in the consuming country—health risks which otherwise would be expected to increase if regional ecological capital were exploited or degraded instead of exploited in other countries. The situation is likely very complicated, however, and factors other than trade, as noted earlier, also contribute to the buffering effect. For example, some human populations, regardless of wealth or trade balance, are more vulnerable to ecologically-mediated risks because of their geographic situation and climate. Policy aimed at reducing future health risks from ecological change will need to consider these factors.

Figure 1. was adapted from Sieswerda et al (2001), and summarizes in diagrammatic form important findings from that study. It shows how, at the country level, the relationship between life expectancy and indicators of ecological integrity (Line A) was negligible; the relationship between indicators of ecological integrity (EI) and gross income (Line B) was moderately strong; and the relationship between gross income and life expectancy (Line C) was strong. The variables used as indicators of EI (such as percent annual change in forest cover and percent of highly disturbed land since pre-agricultural times) suited the operational definition of EI used in the Sieswerda et al study, but there is as yet no scientific consensus on the meaning or most useful indicators of EI.

Figure 1. Relationship between ecological, human health, and gross wealth indicators


Indicators of Ecological Integrity
Negligible relationship (Line A)
Life Expectancy
Moderately strong relationship (Line B)
Strong relationship (Line C)
Per capita Gross Domestic Product

(Source: Sieswerda et al, 2001)

The relational situation outlined by Figure 1. points to several probable features of the causal world which are relevant to this study. These include:

i) Life expectancy as a population health indicator may not be responsive, or not immediately responsive, to variation in ecological integrity at the country level—other, more sensitive human health indicators (such as rates of specific diseases) may need to be developed and measured;

ii) The regularly substantiated correlation between GDP and basic population health at the country level is reaffirmed by this analysis; and

iii) The moderate but not strong relationship between measures of ecological integrity and monetary wealth at the country level, and the inconsistency of the direction of that relationship, suggest the need for further exploration of the ways in which ecological health and monetary wealth are related—including the spatial scales other than national (e.g., local, regional, global) at which the relationship may be more consistent in direction and/or stronger.

Sieswerda et al's findings and points (i), (ii), and (iii) above are all relevant to the consideration of ecologically-mediated health risk buffering. For example, if ecological integrity (as measured by the block of variables used in the study) and population health (indicated, arguably inadequately, by life expectancy) are in some cases more than weakly related, then the problem may lie with the spatial scale of the analysis. If this is so, then we are pointed to at least one way in which ecologically-mediated health risk buffering at the national level may "work"—by deferring the relevant ecological health-human health relationship(s) to another place. Point (i) above also indicates the reality that the boundaries of nation states are not contiguous with the boundaries of ecosystems.

Point (ii) raises the question of how national monetary wealth "causes" population health. Also, given both that the country-level relationship between ecological health and monetary wealth may be inconsistent and that, on the global scale, major ecosystem types are clearly in decline, the usefulness of the nation-state level of analysis is again called into question.

Point (iii) provides a major impetus for the present study's emphasis on some of the distal health impacts of the consumption of farmed Atlantic salmon, since the operation of a global industry often means the concentration of wealth in some countries and impacts on ecological quality in other countries. Further, even within the same country, the relationship between monetary wealth and ecological quality may be indeterminate because no historical and/or appropriate comparative data on the relationship are available—there are too few data points.

Trade, especially in modern products which can be constituted by/with multiple materials and intricate components from many regions of the world, suggests a complex "layering" of the ecological buffering phenomenon. The monetary wealth that one country gains from a production operation in a foreign country (wealth which the consuming country may use to improve its population health) is not necessarily gained entirely at the expense of the producing country's ecological capital. This reality complicates analysis of the buffering phenomenon. The producing country may itself be importing ecological capital from some other nation or nations, in turn buffering its population from the more direct, negative, and self-regulating feedback otherwise connected with degraded regional/local scale ecosystems in the producing country. This complexity does not suggest, however, that country-level accounting of domestic natural capital assets would not be useful. Determination of states and trends in depletion of natural capital assets at the country-level, and of the share of domestic natural capital assets exported to meet market demands in other countries, would enable the identification of key "source" nations for the demands of the global economy.

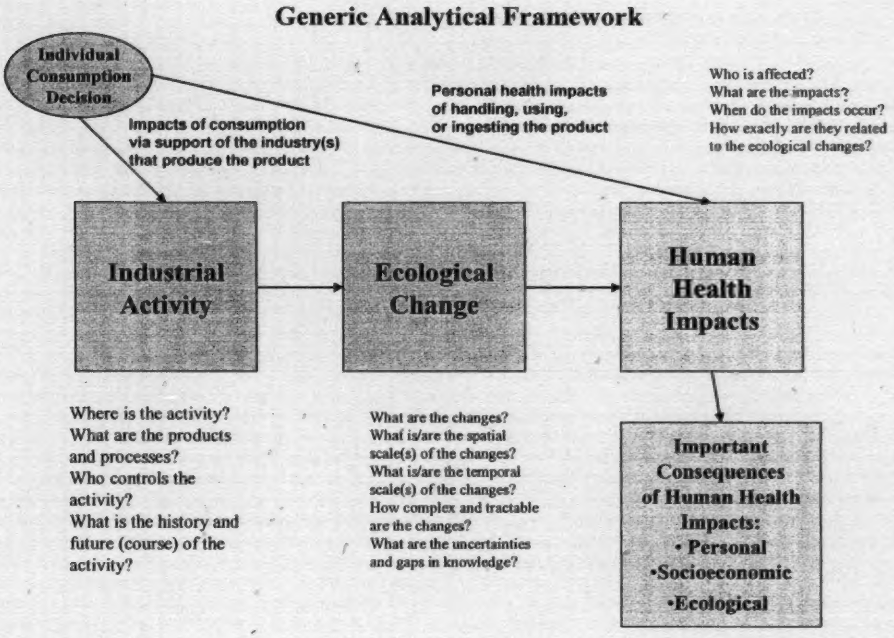
If the world's ecosystems were not linked but discrete and unaffected by what happens to any one of them, and if each of the ecosystems on the earth provided the same suite of functions and services to humans, albeit in different quantities, then it is conceivable that international trade would become such an efficient mechanism of deferring negative intra-national ecological consequences that trade processes would continue until the last hectare of ecological space on the planet was exhausted in the interest of wealth generation through the production and sale of goods. Once that last hectare of the last ecosystem providing the functions and services needed by human beings was exhausted, the entire human population, and all the societies in which it is distributed, would collapse (Rees, 2006). This process, or at least a less than perfect version of this process that results in some regional ecological collapses along the way, but which leads towards increased production to the point of large-scale collapse, stands in contrast to the traditional environmental "Kuznets curve" which reflects the theory that environmental quality is a luxury good which will be in demand (and therefore producible) only once a society has reached a certain level of economic development (Grossman and Krueger, 1995).

This extreme scenario is unlikely, in part because there are overarching global-scale processes at work (such as the warming of Earth's surface from the increased concentration of CO_2 in the atmosphere) that impact all ecosystems on Earth. Thus, the planned exploitation of ecological capital through strategic economic activity is not the only factor determining the amount of degradation sustained by the ecological support base. However, modern trade arrangements do make possible a wider range of exported and imported commodities, and faster flow of investment into and out of countries than was previously the case. This suggests that within some chains or webs of buffering, more ecosystems in more locations on Earth may be pressed to collapse than would be the case in a less spatially expansive economy. This hypothesis will not be tested directly in this study.

1.10. Other tools for evaluating the impact of human economic activity on the ecosphere

Figure 2. below shows how a theorized flow of causes and consequences moving from economic production/consumption through to human health impacts on a global scale may be visualized. Figure 13. in Chapter 4 can be understood as a detailed illustration of one of many cause-and-effect webs, for a specific industry, that could exist in the broader context of Figure 2.

Figure 2. Generic analytical framework


Generic Analytical Framework
Individual Consumption Decision
Impacts of consumption via support of the industry(s) that produce the product
Personal health impacts of handling, using, or ingesting the product
Who is affected?
What are the impacts?
When do the impacts occur?
How exactly are they related to the ecological changes?
Industrial Activity
Ecological Change
Human Health Impacts
Where is the activity?
What are the products and processes?
Who controls the activity?
What is the history and future (course) of the activity?
What are the changes?
What is/are the spatial scale(s) of the changes?
What is/are the temporal scale(s) of the changes?
How complex and tractable are the changes?
What are the uncertainties and gaps in knowledge?
Important Consequences of Human Health Impacts:
• Personal
•Socioeconomic
•Ecological

Ecological Footprint Analysis (EFA) has already been described as a tool for determining the gross ecological sustainability of a human enterprise, and the value of disaggregating the EF, in order to identify specific ecosystems being impacted, also has been noted. Conceptual and analytical tools other than EFA are then needed to help identify the human health impacts that stem from the ecological impacts identified in an aggregated or disaggregated EFA. These tools may ultimately also clarify the role of consumption in affluent nations such as Canada in the web of system drivers that generate specific health risks (exposures) as well as specific health benefits for particular populations in producer countries. The next section describes and critiques several of these analytical tools.

1.11. Methodological approaches

1.11.1. DPSEEA (Driving forces–Pressures—States—Exposures—Effects—Actions)

Around the year 2000, the World Health Organization (WHO) began using the DPSEEA framework for understanding complex systems that affect human population health. Closely related and foundational to the DPSEEA framework is the Pressure-State-Response (PSR) framework. Seen through the lens of PSR, the (aggregated) EFA approach discussed earlier is basically a "PS" approach, since it aims to identify the human load (Pressure) on Earth's ecological capacity, and to determine if that load creates a non-sustainable "State." The DPSEEA framework, in comparison, directs the researcher to look further upstream (to Driving Forces) and further downstream (to Exposures, Effects, and Actions). Almost any human activity, and especially those of a large-scale, can be understood through the lens of the DPSEEA framework. For example, Kjellstrom and Hill (2002) applied the framework to the analysis of transport-related health impacts in New Zealand, noting Driving forces such as population growth and an increased demand for transport from a growing economy; Pressures such as more cars and trucks on the road, more noise, and more toxic emissions; States such as diminished air quality and more congested roads; Exposures such as air pollutants and physical traffic risks; Effects such as respiratory problems and injuries and fatalities from traffic accidents; and a range of Actions including educational initiatives and changes in legislation. Theoretically, any of the elements in the DPSEEA framework can be the point of entry for investigation; a researcher might be aware of (E)ffects , and then look both retrospectively to determine (E)xposures, (S)tates, (P)ressures, and (D)rivers, and prospectively towards effective (A)ctions. However, the elements of the DPSEEA framework are connected by positive and negative feedback loops and are not necessarily connected in a linear fashion. Thus, for example, an Effect may change the States or Pressures in other parts of the framework. Because the DPSEEA framework is understood mainly as an environmental health framework, the WHO (1999) does caution that it is less useful (or at least must be carefully adapted) in situations involving physical risks where "Pressure" is less meaningful. These include risks posed by natural hazards and technology (e.g., automobiles, as in the Kjellstrom and Hill study) and those risks which have very complex developmental histories.

The DPSEEA framework is oriented towards public health *action*, as informed by improved understanding of the underlying forces that perpetuate or amplify certain health conditions. It is a tool for thinking in a systemic way about the relationships among exposures, outcomes, and their causal antecedents. It is primarily qualitative in nature, though some links between nodes of the causal pathways that it illustrates may be quantified. DPSEEA is also useful for structuring a broadly causal description of a particular economic enterprise and its health impacts, since it necessitates looking at historical features that affect both present and future exposure contexts, and it helps locate the industry within a milieu of positive and negative feedback loops. The DPSEEA framework does not provide a particular method for analyzing or interpreting the most relevant features of the relationships it describes, but it does suggest which areas need more research attention and it identifies potential points of intervention. It also provides a larger context in which aggregate measures of ecological Pressure, such as the Ecological Footprint, may be located. When understood as a kind of Pressure, the associated States, Exposures, and Effects of an aggregated or disaggregated Ecological Footprint can then be sought.

1.11.2. (Product) Life-Cycle Analysis

Product Life-Cycle Analysis (PLCA or LCA) grew out of the field of global energy audits in the 1960s and 1970s as a means of improving process efficiency in production, reducing costs and wastes, and minimizing certain types of environmental impact (Ciambrone, 1997). LCA is useful as a tool for understanding a product's impact in more ecological or systemic terms, but only the relative efficiency (e.g., CO_2 emissions per unit produced) and not the absolute sustainability of operations can be shown. LCA generally does not go as far as EFA in that it focuses on emissions and gross material and energetic demands throughout a product's life-cycle, not on the ecological implications (such as the area of global bio-productive space consumed) that EFA supplies. For example, a sample LCA data collection sheet from the International Standards Organization (ISO, 1998) recommends quantifying emissions to air, water, and land, among other "impacts." LCA as currently structured can help define Drivers and Pressures (see the DPSEEA model), but typically not States, Exposures, or Effects. For the purposes of this study, the concept of LCA is important to the task of disaggregating the EF of the GFASI and spatially and temporally locating ecological impacts. Products of the aquafeeds industry, which supplies Atlantic salmon farms with a major input, have undergone LCA (Papatryphon et al, 2003).

1.11.3. I=PAT

I=PAT specifies that environmental Impacts (I) are the product of Population (P), Affluence (A = per capita consumption or production), and Technology (T = impact per unit of consumption or production) (York et al, 2003). For several decades the I=PAT equation has served as a focus for dialogue about the relation between key factors contributing to the aggregate impacts on the planet of modern human life. "Impact" also can be construed as "ecological integrity," insofar as the human enterprise on Earth is a factor in preserving or diminishing that integrity. In fact, each of the terms is open to multiple operational definitions, and the mathematical relationship between them remains a topic of ongoing debate.

Additionally, the "I" side was originally understood to be "pollution" or "emissions," not the sum of all types of environmental impact, and not a measure of global ecological integrity or carrying capacity. The equation does not suggest what kind or amount of "I" is desirable or how much "I" Earth can sustain. As such, it has limited value as a tool for informing environmental policy; it has more value as a conceptual framework for understanding the interdependence among core drivers of human impact on the ecosphere. The most important value of the I=PAT equation to the field of public health, and to eco-epidemiology, is that it shows that while continuing population growth, overconsumption and poor waste management, and the expansion of high-impact technologies may be relatively more or less important as risk factors for specific population health problems (for example, population alone increases certain risks if population density becomes extremely high), they cannot be treated independently for most human health problems of environmental or ecological origin. Also the I=PAT formulation is useful for framing discussions about global ecological decline because it underscores the impropriety of singling out any single factor for attention over any other factor.

The I=PAT equation has been reformulated in stochastic terms. Dietz and Rosa (1998) called the new version "STIRPAT" (Stochastic Impacts by Regression on Population, Affluence, and Technology). The reformulated version allows some hypothesis testing, since it takes the form of a multiplicative regression equation that includes "T" (Technology) as the error term, since what constitutes and indicates technology remains open to debate.

The stochastic version of I=PAT could be rearranged to allow for the inclusion of health-related terms, such that an environmental impact, "I," would then stand in relationship to P, A, and T and be a contributing factor to a health outcome. However, additional terms would need to be conceptually consistent with the multiplicative specifications of the model (York et al, 2003).

1.11.4. Classical epidemiological approaches (PICO and PEO)

In epidemiological studies conducted to determine associations between exposures and morbidity or mortality endpoints (outcomes) based on historical data, sound scientific method requires that, for intervention studies, the Population, Intervention, Control (group), and Outcome(s) must be clearly defined. Conclusions are suspect if these elements are not well defined and controlled. In population-based studies, the Population, Exposure of interest, and Outcome(s) must be similarly clear. Again, unrecognized bias and misleading conclusions are likely to result if these three elements are not well-defined and measured.

Investigations of the links between economic activities that generate ecological externalities, and the human health consequences of those externalities, are natural experiments with no controlled Intervention (I) component. However, the Population, Exposure, and Outcome elements of PEO might be defined. For a particular population, historical measures of specific ecological conditions, and outcomes sensitive to those conditions, could be measured and compared with outcomes in that same population subsequent to specified changes in the original conditions. For example, individuals directly depending, for a substantial portion of their protein needs, on fish caught by local artisanal fishers could be assessed for nutrition-related disorders before and after major human interventions (such as overfishing in the industrial sector) which are known to affect marine ecology and thus the abundance of some fish species relevant to those individuals relying on the artisanal catch.

While the PEO approach could be usefully applied to some problems in the eco-health field, its orientation towards individual-level exposure data presents a challenge for investigating effects in populations where everyone is exposed to the same ecological conditions, or where no sensitive indicators exist of individual-level response to the ecological change(s) of interest.

In sum, the selection of methodological approaches discussed in sections 1.11.1. through 1.11.4. represent different ways of conceptualizing and addressing eco-health problems. Methodological development for future case studies might include the synthesis of these methods, and others not discussed here, into a transdisciplinary research context.

The next chapter reviews conceptual and contextual literature related to the key components of this study.

Chapter 2. Review of Contextual and Conceptual Literature Relevant to the Global Farmed Atlantic Salmon Industry, Peruvian Society, and the Accounting Framework

2.1. Outline of this chapter

This chapter begins with a narrative that shows how the consumption of a serving of farmed Atlantic salmon is or may be implicated in a complex web of ecological and human health consequences. Then, the context in which our research proposition is embedded is described through a review of the literature on the basic features of global aquaculture, salmon farming in general and the global farmed Atlantic salmon industry (GFASI) in particular, and the reduction fisheries that supply fishmeal and fish oil to the GFASI. This chapter sets the context for our research proposition, which is described in Chapter 4 (Methods) and is illustrated by the schematic in Figure 13.

The research proposition suggests a number of causal relationships between variables that culminate in specific types of population health impacts realized in a country (Peru) which is at a great geographical distance from those nations that together constitute the bulk of the global demand for farmed Atlantic salmon. The literature review in this chapter brings our study up to the point at which demand for fishmeal and fish oil by the GFASI implicates the Peruvian anchovy fishery; discussion of the consequences flowing from that fishery are discussed in Chapter 5 (Results), since at that point the proposed causal story has moved from a description of the features of the larger GFASI to the particular implications for ecologically-mediated population impacts in Peru. The present chapter does include, however, a review of some characteristic features of Peruvian society that provide context for our later consideration, in Chapter 5, of a range of variables considered to be important in defining the relationship between the Peruvian anchovy fishery and ecologically-mediated population health impacts in that country.

This chapter also introduces an accounting framework for determining the ecologically-mediated population health impacts of specific global industries, and includes a selective review of the literature relevant to the construction of this framework. Consideration of additional conceptual and practical issues in the development of the accounting framework, which constitute part of this study's unique contribution to the field, is left to Chapter 5 (Results).

2.2. From plate to ocean: tracing nodes of the proposed causal web

A single consumer eating a serving of farmed Atlantic salmon participates in a complex web of relationships that together constitute the total ecological, economic, and socio-cultural impress of the global farmed Atlantic salmon industry. A consumer may or may not know that she is eating farmed (as opposed to wild) salmon; thus, even from the outset of a "consumption event," a consumer may not know within which web of relationships (the one pertaining to farmed Atlantic salmon or the one pertaining to wild salmon) her action has effect. Ultimately, both webs are linked, since wild salmon stocks are affected by changes in the farmed Atlantic salmon industry, such as expansion along coastal zones, regional ecosystem impacts affecting all aquatic life, and escapes of farmed Atlantic salmon and eventual interbreeding with wild stock.

Let's assume that the serving of farmed Atlantic salmon, say 100g, was consumed as sushi in a restaurant in Edmonton, Alberta, Canada. The diner's purchase of the farmed Atlantic salmon from the menu required the immediate supplier (the restaurant) to purchase the farmed Atlantic salmon from another supplier. The salmon had to be transported from the salmon farm to that supplier, requiring the combustion of fossil fuels to move the transport vehicles (e.g., airplanes and trucks) containing the farmed Atlantic salmon. If the salmon farm was located along the south coast of British Columbia, then the salmon would have to travel approximately 1,200 km to the point of consumption. In theory, the energy requirement for transporting the single salmon serving could be calculated, provided the types of transportation, efficiency of combustion, and the total volume of salmon being moved (so that the portion of the energy required to move a single serving could be calculated) were known entities. Carbon dioxide emissions, and the emission of other greenhouse gases associated with transporting the salmon, also could be estimated.

The Atlantic salmon farm in which the salmon was cultivated consists of physical infrastructure (e.g., net cages, platforms, predator nets, lights, and machinery to move fish and distribute feed), or "built capital" in GPI accounting (Anielski, 2001), as well as human workers and the principal biological resources in the operation: salmon at various stages of development, feed pellets derived from fishmeal and fish oil as well as legumes and cereals such as soy, corn, and wheat. Other ingredients include vitamins, dyes, binders, and minerals. Each ingredient has its own life-history, and the production and manufacture of each ingredient consumes energy and resources.

Each of the infrastructure elements that constitute the salmon farm has its own industrial or biological life-cycle, and thus each element has an associated environmental impact based on the materials and energy (including biotic resources like other fish) used to produce it. Consider as an example just one piece of physical equipment common on salmon farms: net cages. The consumer eating the serving of farmed Atlantic salmon in Edmonton indirectly supports, by their restaurant choice, the producers of the raw materials used in the construction of the net cages; the manufacturers and distributors of the net cages; and the industry that will deal (for a price) with the net cages once their useful life is over. According to Tyedmers (2000), the main structural members of a cage system may be composed of steel, aluminum, plastic or wood, depending upon the age, size and type of cage system used. A variety of raw materials (e.g., aluminum, oil or natural gas, trees) and the energy used to process these materials could be involved in the production of net cages. Modern industrial and manufacturing enterprises typically use parts, chemicals, and other inputs from multiple suppliers (potentially in multiple countries) which extends the global reach of the diner's consumption decision.

At the grow-out site for the farmed Atlantic salmon in British Columbia, regional/local scale ecosystems are impacted. Commonly mentioned concerns include the spread of parasites such as sea lice to wild salmon; interbreeding between escaped farmed Atlantic salmon and wild salmon stocks, leading to reduced genetic fitness in the wild populations; the intensive and extensive use of antibiotics in the farmed fish, potentially creating antibiotic resistance in those fish; and the degradation of benthic communities underneath the net cages (Georgia Strait Alliance, 2006; Volpe, 1996). The consumption of a serving of farmed Atlantic salmon implicates these impacts, however great or small they may be, and with whatever implications for human health, through the financial support of the producing enterprise.

The individual consumption decision of the diner in Edmonton is quickly showing an expansive network of energetic and material connections through the economic actors required to produce and transport the product being consumed. Assuming that the fishmeal constituent of the feed pellets being fed to the Atlantic salmon contain a large proportion of anchovies, and that these anchovies were fished from waters off the coast of Peru, the consumer now becomes implicated in a web of economic, energetic and material, and ecological relationship with the anchovy fishery of Peru, as well as with the fishmeal and fish oil processing operations in that country. Thus, a potential source of high-quality protein from Peru has been (indirectly) served to a diner in Edmonton. In return, a Peruvian fishing enterprise and particular Peruvian fishers are remunerated. With that money, these fishers may be able to buy other foods, including fish caught in Peruvian waters or imported from other countries. Personal income and other micro- and macro-level features of employment in the Peruvian anchovy fishery, which likely are relevant to human health (such as job stress, mass layoffs during fish stock collapses, and corporate consolidation), are also indirectly affected by our diner's consumption decision.

By eating fish fed with fishmeal and fish oil produced from Peruvian anchovies, the diner thus also consumes a share of the energy and materials used by the Peruvian anchovy fishery, as well as a share of the bioproductivity of the Humboldt Current Upwelling Ecosystem (HCUE) off coastal Peru. Since anchovies feed on smaller zooplankton and other organisms, our diner in Edmonton is in effect eating a portion of the energy originally contained in these organisms. The consumption of other products traded globally, or involving inputs that are traded globally, likewise implicates material and energy resources and ecosystem impacts in distant locales. The consumption of each product involves a different distribution, and thus a different set of ecological impacts with related human health implications.

Because anchovies must be processed into fishmeal and fish oil, which then are used as ingredients in the feed pellets that are eventually fed to the farmed salmon, the diner in Edmonton also consumes a portion of the energy and materials used to sustain the fishmeal and fish oil processing plants in Peru—as well as the energy and materials used to package and transport that fishmeal and fish oil to another plant that will mix the meal and oil with other ingredients—as noted above—to make finished farmed salmon feed pellets. The diner will also then consume some of the energy that goes into, and some of the energy that is concentrated in the biomass that comes out of the modern agricultural enterprise responsible for producing the other ingredients (like corn or soy) in the farmed Atlantic salmon feed pellets.

Other actors and resources are peripherally involved with the diner's consumption action. For example, the collective demand for farmed Atlantic salmon products, to which the diner contributes, sustains the industry in British Columbia. Any industry with regional economic and ecological implications requires regulation by government. Thus, legislators must spend time making regulations, and time and energy is also devoted to enforcement associated with those laws.

Decisions about what to include and what to exclude in this narrative were arbitrary. The goal is to show that, from specific acts of consumption in North America, there are few straight lines of causation to distal ecological and health impacts in other areas and populations. However, there are likely some of these lines for some products. This illustration merely shows some of the relationships that could be investigated, and it also highlights one of the key problems we face by making our global economy so complex: responsibility for ecological damage, and for any associated population health harms, can rarely be placed on a single person or entity. In criminal law, where a person or simply property has been harmed, we depend heavily on this kind of attribution for making convictions and deciding on sentencing. Different ways of attributing responsibility are implied in the present context.

2.3. Literature review: global aquaculture

According to the Food and Agriculture Organization (FAO, 2000), aquaculture is the farming of aquatic organisms, including finfish (both herbivores, such as some carp species, and carnivores, such as Pacific and Atlantic salmon), shellfish (mollusks and crustaceans) and aquatic plants such as seaweed. It implies some form or intervention or exertion of control in the rearing process to enhance production. This may include regular stocking, feeding, and protection from predators, as well as special husbandry in certain parts of the organism's life-cycle (Anderson, 2002). Aquaculture also implies individual or corporate ownership of the cultivated stock, in contrast to most capture fisheries which involve a common property, open-access resource that is only partially regulated. Mariculture refers to saltwater aquaculture, but aquaculture projects are conducted in brackish water and freshwater environments as well. Most Atlantic salmon are farmed in mariculture environments, but many countries, including Canada, include operations that take place in brackish water and even freshwater environments (FishStat, 2004).

Fish, molluscs, crustaceans, and other aquatic animals (hereafter "fish," unless particular species or categories of fish are noted) produced through aquaculture constitute a growing proportion of the total volume of fish consumed by humans. Global aquaculture production more than doubled by weight and value from 1989 to 1998 (Goldburg et al, 2001) and increased by more than 11% per year between 1985 and 1997 (Delgado et al, 2003). Anderson (2003) quotes a growth rate of 13% per year in the 1990s specifically. From 2000 to 2004, production of food fish from aquaculture has grown by about 6% per year (FAO, 2004), a slight slowing since the boom decade of the 1990s. In 1997, global food fish production from aquaculture comprised 31% of total fish production; only several years later, that proportion is estimated at 40% (Naylor and Burke, 2005). In some countries such as the United States, growth in mariculture, especially of finfish, is retarded by the lack of suitable near-coastal sites (Goldburg et al, 2001). As a result, prospects for offshore aquaculture operations have become more attractive in these countries.

The FAO (2000) estimates that nine million people labour in the aquaculture industry globally. As with capture fisheries, aquaculture production consists of numerous small producers and a small number of very large firms. In the fish feed manufacturing sector, large firms dominate. For example, more than two-thirds of the total global production of salmon aquafeed is produced by two companies, Skretting and Cermaq (Tacon, 2005). These two firms also are integrated with fish feed producing operations--the fish feed company EWOS, for example, is a division of Cermaq. Recent consolidation in the production side of the farmed Atlantic salmon industry suggests increasing monetary wealth concentration in the industry; for example, as of late 2006, the company Pan Fish accounted for nearly 30% of the global production of farmed salmon species (Intrafish, 2006b).

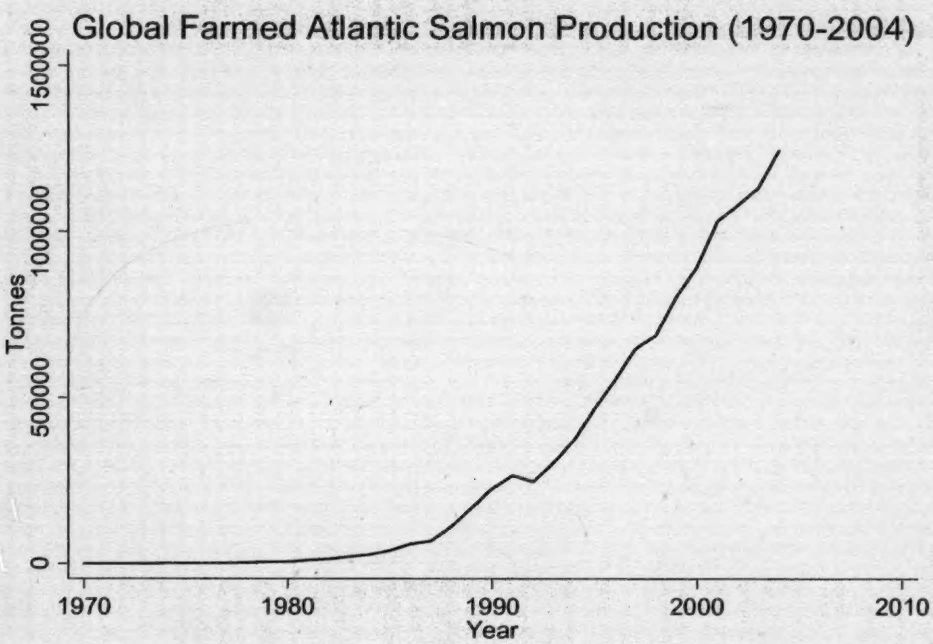
2.3.1. Literature review: salmon farming

The cultivation or farming of salmon began in order to maintain a supply of salmon to consumers when wild salmon catches were unpredictable, or simply to produce a product comparable to the wild version at lower cost. It might be argued that the primordial driver of the GFASI is not consumer demand for farmed salmon *per se*, but both consumer demand for a consistently available source of salmon and a variety of processed salmon products, and the profit motive.

The farming or cultivation of salmon dates back to the late 1960s, when the first commercial operations began production in Norway. In the next few years, small operations were also started in the United States and in British Columbia, Canada. However, even by 1972, the total production of Norway's five farms combined was only 46 tonnes (SeaWeb, 2006). By 1980, global farmed salmon production was just over 7,000 tonnes and accounted for approximately 1% of the world salmon market. Several years later, farmed Atlantic salmon (*salmo salmar*) had become the primary farmed salmon species, even though Pacific salmon such as coho are still farmed at nearly 10,000 tonnes per year (FishStat, 2004). Chilean farms currently are responsible for the large majority of global farmed Pacific salmon production.

By 1987, global farmed salmon production (all species) was 13 times as great as it was in 1980, and farmed salmon was gaining an increasingly large share of the total (wild caught plus farmed) global salmon market. Growth in the industry continued throughout the next decade, until in 1999, for the first time in history, global farmed salmon production—nearly 1,000,000 tonnes—surpassed the wild salmon catch. Figure 3. shows the increase in global farmed (Atlantic) salmon production from 1970 through 2004.

Figure 3. Global farmed Atlantic salmon production



FishStat, a universal software program for basic fish statistics developed by the FAO, includes production data for the 19 countries involved in Atlantic salmon farming in 2004. Farmed Atlantic salmon production, by each of these countries for the calendar year 2004, is indicated in Table 3. below. We could not obtain information on the proportion of each country's total production of farmed Atlantic salmon that was exported versus consumed domestically.

Table 3. Farmed Atlantic salmon production by country (2004)

Country	**2004 production of farmed Atlantic salmon (tonnes)**
Norway	565,902
Chile	349,329
UK	158,099
Canada	82,374
Faeroe Islands	37,296
USA	15,127
Australia	14,828
Ireland	14,067
Iceland	6,624
France	735
Russian Federation	203
Spain	30
Denmark	16
Greece	7
TOTAL 2004 PRODUCTION	1,244,637

The global geographic distribution of Atlantic salmon farming operations is uneven, with virtually no production in Africa and Asia, primarily because the water conditions are not suitable. Many countries, such as Sweden, which cultivated salmon during the mid-1980s or mid-1990s no longer have substantial operations. Figures 4., 5., 6., and 7. show some of the variation in national production trends over the past 20 years. For countries such as Norway, Chile, and Canada, growth has been relatively steady and rapid. Some countries, such as Greece, have all but abandoned production. In the case of Greece, it is likely that other farmed fish species, such as sea bass and sea bream, which are ideally suited to the warmer Mediterranean waters surrounding that country (Kahn, 2004), displaced species such as Atlantic salmon for which production conditions were sub-optimal. The downturn in Canadian production towards the more recent years of production likely reflects, in addition to heightened public concern over several controversial issues in farmed Atlantic salmon production, the moratorium that was placed by the British Columbian government on new farm site licenses in that province in 1995 (David Suzuki Foundation, 2002).

Figure 4. Norwegian farmed Atlantic salmon production

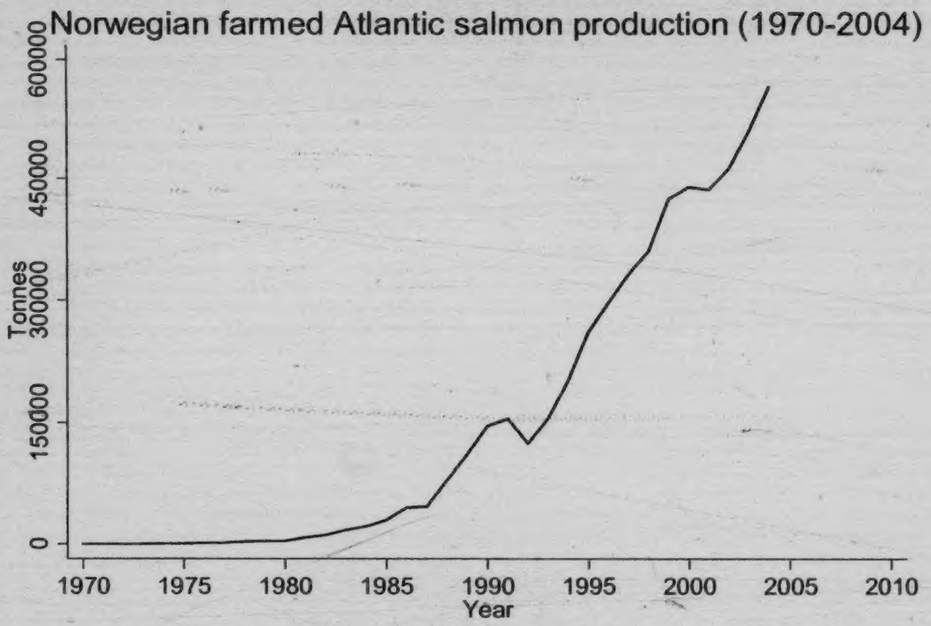


Figure 5. Chilean farmed Atlantic salmon production

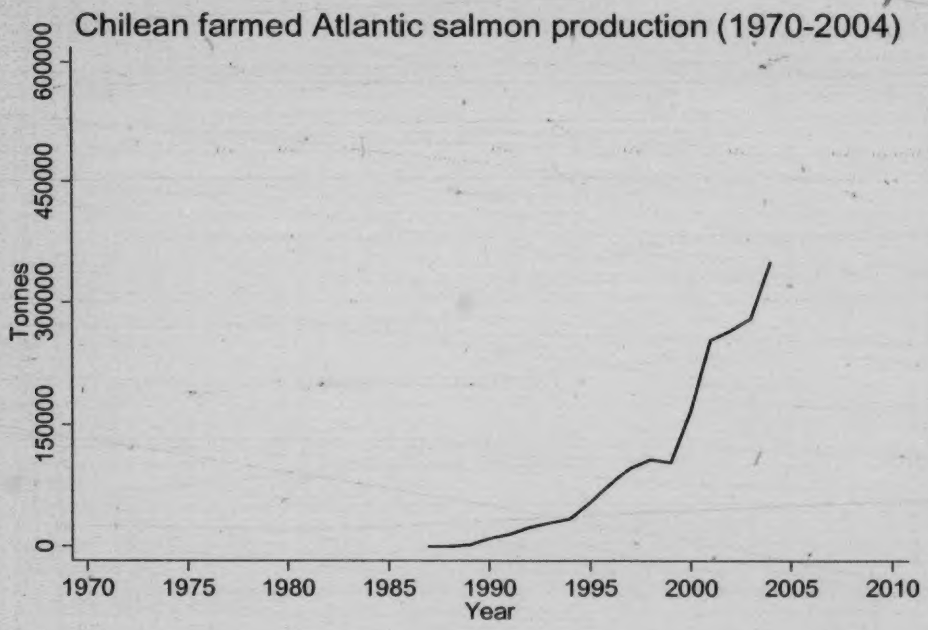


Figure 6. Canadian farmed Atlantic salmon production

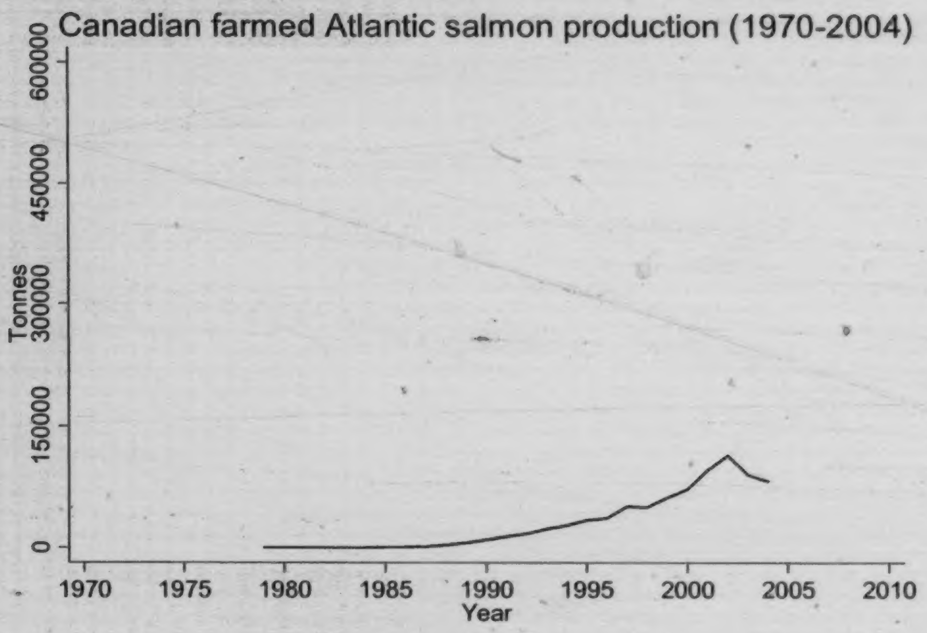


Figure 7. Grecian farmed Atlantic salmon production

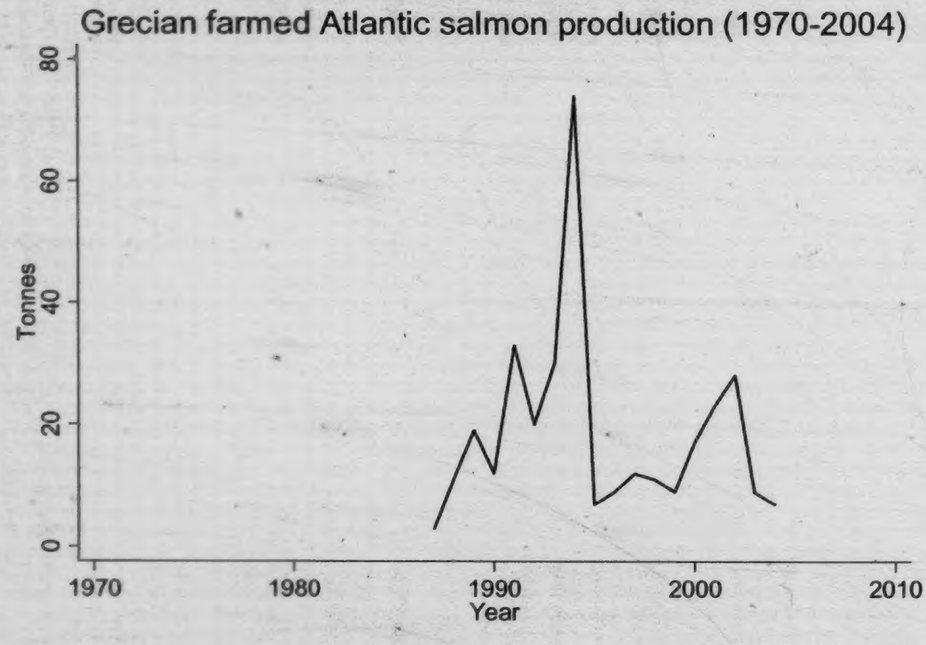


Table 3. shows that Norway and Chile together are responsible for about three-quarters of the world's farmed Atlantic salmon production. Chile and Norway are also, respectively, the first and second largest producers of fishmeal and fish oil in the world (see section 4.2.2.). Farmed Atlantic salmon in all environments (brackish water culture, freshwater culture, and mariculture) constituted approximately 2% of global aquaculture production by weight in 2002 (FishStat, 2004; FAO, 2004). By value, in that same year, the species accounted for approximately four times that proportion in the international aquaculture market (FishStat, 2004; FAO, 2004). China is the largest producer of cultivated aquatic organisms in the word, but most of this production consists of herbivorous species such as some of the carp species, and is consumed domestically. Feed demands can largely be met through organic matter in the local environments of the cultivated species—unlike the feed demands of farmed Atlantic salmon.

As noted above, both Atlantic (*salmo salmar*) and Pacific (various species) salmon are farmed, although worldwide the production of Atlantic salmon is much greater. Atlantic salmon is farmed primarily under an intensive husbandry process that includes control over hatching, spawning, feeding, and protection from predators. Typically, young salmon are hatched and nurtured through the smolt phase in land-based facilities, then transferred to large near-shore net cages for the "grow-out" phase until they are ready to harvest for market. During the grow-out phase, the primary concerns of the salmon farmer are to keep predators at bay, prevent escapes, prevent and manage disease outbreaks (infections, parasites), maintain feeding regimens and keep feeding efficient, and limit impacts on the local marine environment from salmon and feed waste. Failures or compromises in any of these areas have ecological impacts which are usually noticed at local or regional scales (e.g., benthic "dead zones" under salmon net cages, escaped salmon breeding with native species in regional rivers, and spread of parasites into surrounding waters) (Georgia Strait Alliance, 2006; Volpe, 1996).

2.3.2. Literature review: the reduction fisheries

The fisheries that provide the fish biomass which is converted into fishmeal and fish oil and eventually incorporated into farmed salmon feed pellets, the so-called "reduction" fisheries, are critical to the production of farmed Atlantic salmon. Fishmeal and fish (body) oil are the largest biological inputs, by weight, and together constitute the largest cost, in farmed Atlantic salmon production. Fish body oil is distinguished from fish liver oil; the latter is marketed mostly as a human nutritional supplement and is likely to be extracted from species such as cod which are not usually used for reduction purposes.

Total global production of fishmeal and fish oil has remained relatively steady from 1970 to the present, the period for which we have data on the GFASI. In 2004, Peru was still the world's largest producer of fishmeal and fish oil, accounting for nearly 2,000,000 tonnes of fishmeal and 352,000 tonnes of fish oil, or approximately 35% of the global production of fishmeal and 38% of the global production of fish oil. Tables 4. and 5. below show the top 16 fishmeal and fish oil producing countries in 2004. Table 4. also includes data on the approximate weight of domestically produced fishmeal exported and imported, as well as the approximate weight of fishmeal consumed domestically; complete complementary data on fish oil were unavailable. All numbers reported in Table 4. are from IFFO, 2005. Data were available only for the top 16 countries under each column heading, which explains the Not Available (N/A) designation in many cells. Domestic consumption should equal domestic production minus exports plus imports. However, many discrepancies exist and the sources of these discrepancies were not determined.

Table 4. Top fishmeal producing countries (2004)

Country	**2004 production of fishmeal[1] (tonnes)**	**2004 production of fishmeal exported (tonnes)**	**2004 fishmeal imported (tonnes)**	**2004 fishmeal consumed domestically (tonnes)**
Peru	1,983,000	1,751,000	N/A[2]	234,000
Chile	933,000	494,000	N/A	467,000
Thailand	403,000	N/A	N/A	409,000
China	400,000	38,000	1,147,000	1,528,000
USA	353,000	141,000	71,000	222,000
Japan	295,000	N/A	402,000	703,000
Denmark	259,000	247,000	132,000	143,000
Norway	215,000	61,000	162,000	309,000
Iceland	204,000	223,000	N/A	N/A
South Africa	114,000	N/A	N/A	101,000
Spain	103,000	N/A	105,000	185,000
Ecuador	85,000	43,000	N/A	N/A
Russian Federation	70,000	33,000	55,000	103,000
Faeroe Islands	68,000	26,000	N/A	N/A
Morocco	63,000	34,000	N/A	N/A
Mexico	55,000	N/A	N/A	75,000
UK	51,000	6,000	143,000	188,000
TOTAL 2004 PRODUCTION	5,654,000			

[1] Production of fishmeal is assumed to be constituted entirely by fish caught in domestic waters or in nearby waters in which several countries operate (e.g., the North Sea in the case of Norway)

[2] N/A: Data not available

Table 5. Top fish oil producing countries (2004)

Country	2004 production of fish oil[1] (tonnes)
Peru	352,000
Chile	138,000
USA	81,000
Denmark	68,000
Japan	68,000
Iceland	49,000
Norway	37,000
Morocco	25,000
Spain	22,000
Turkey	14,000
Ecuador	14,000
China	13,000
Mexico	12,000
UK	12,000
Faeroe Islands	11,000
Russian Federation	4,000
TOTAL 2004 PRODUCTION	920,000

[1] Production of fish oil is assumed to be constituted entirely by fish caught in domestic waters or in nearby waters in which several countries operate (e.g., the North Sea in the case of Norway)

From Table 4., we can see that countries such as the USA, Denmark, and Norway all produce and consume fishmeal in large quantities, while both exporting and importing large volumes of the product. Iceland uses very little fishmeal domestically and exports virtually its entire domestic production; in contrast, the UK produces relatively little fishmeal domestically, but is a large consumer and thus relies heavily on imported fishmeal. Chile is unique in that it consumes a large volume of fishmeal domestically, but, because of substantial domestic fishmeal production, is still able to export about half of its domestic fishmeal production. Data such as those provided in Table 4. provide a starting point for determining the inflows and outflows of specific elements of natural capital (such as small pelagic fish stocks and flows) from specific countries.

Because the primary distal ecological impacts of the global farmed Atlantic salmon industry are likely to come from the reduction fisheries that supply the key input (feed pellets) to farmed Atlantic salmon grow-out operations, the geographical distribution of these fisheries and other basic features warrant mention.

According to Asche and Tveterås (2004), the reduction fisheries in Chile and Peru account for more than 50% of global fishmeal and fish oil production, an estimate which is supported by the values in Tables 4. and 5. Most fishmeal and fish oil is processed in the country having jurisdiction over the waters from which the fish were captured, but the majority of both commodities is exported (IFFO, 2005). For the top fishmeal producing countries (see Table 4.), exports constitute about 55%. Thus, the transportation of fish to fish processing plants is largely a within-country phenomenon, while the transportation of processed fishmeal and fish oil to markets is mostly international. Global fishmeal and fish oil production is distributed among several very large-volume producing countries and numerous very small-volume producing countries. Fishmeal consumption varies widely among countries, as does fish oil consumption. In 2004, China consumed more than twice the fishmeal (1,528,000 tonnes) of Japan, the next largest consumer at 703,000 tonnes (IFFO, 2005). Other major consumers were Chile, Thailand, and Norway. The consumption of fish oil by country reflects in part the special importance of this commodity in the feed for farmed salmon and other carnivorous marine finfish: Chile and Norway are the world's top consumers of fish oil, and these countries are also the top producers of farmed Atlantic salmon.

Fish oil, and not fishmeal, is the limiting factor in farmed Atlantic salmon feed. The protein content of fishmeal can be substituted by other high-protein animal and plant sources, but fish oil naturally contains micronutrients such as Omega-3 fatty acids in greater concentrations than most other animal and plant products (Fishmeal Information Network, 2001). The International Fishmeal and Fish Oil Organization (IFFO) estimates that while global aquaculture is expected to consume half of global fishmeal supply by 2010, it is expected to consume 97% of the total fish oil supply (IFFO, 2001). If this prediction is realized, in only a few years this would tie the carnivorous marine finfish segments of the global aquaculture sector even more directly to the productivity of the world's reduction fisheries.

Historically, part of the fishmeal and fish oil component of the feed pellets used in the farmed Atlantic salmon industry in Canada has contained Peruvian anchovies. Figure 8. shows the trends in Peruvian anchovy catch and in Canadian farmed Atlantic salmon production since the onset of the Canadian industry. To be meaningful as a preliminary sign of the relationship between Peruvian anchovy production and Canadian farmed Atlantic salmon production, the association between the lines describing these trends would need to account for many other influential trends, such as the proportion of anchovy content in Peruvian fishmeal and fish oil, and the proportion of total Peruvian fishmeal and fish oil output which is consumed by the farmed Atlantic salmon industry in Canada. Also, regarding the proposed contribution of farmed Atlantic salmon producers such as Canada to ecological change in Peru, the dramatic drop in Peruvian anchovy production during the period 1995-1998 needs to be better understood. Natural cyclical events are relevant; El Niño events in 1994-95 and 1997-98 are certainly implicated (Chavez et al, 2003).

Figure 8. Peruvian anchovy and Canadian farmed Atlantic salmon production, 1975-2004

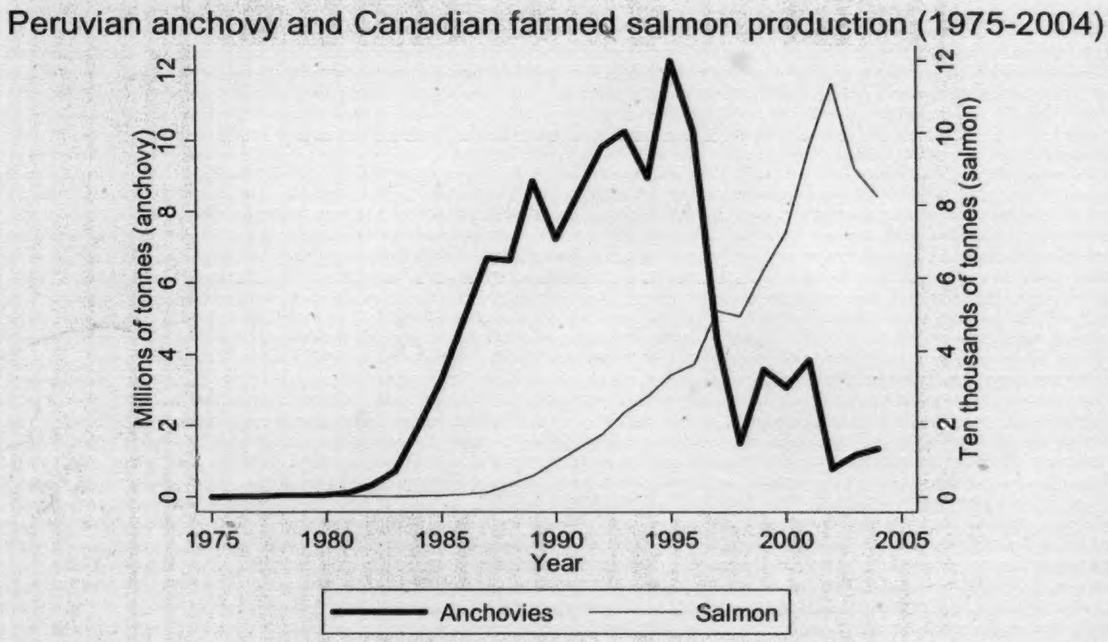
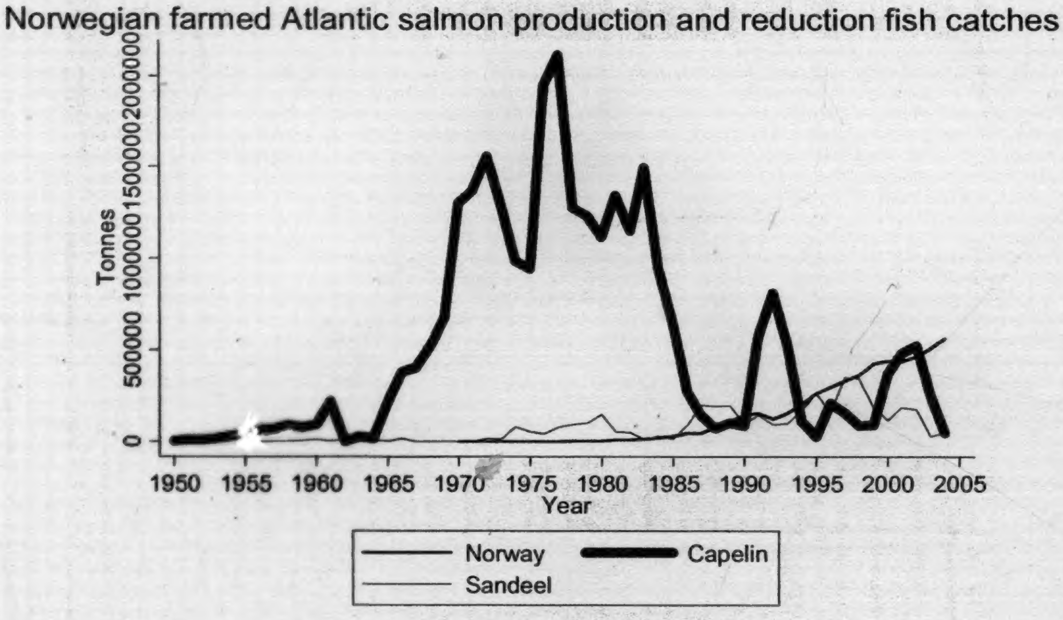


Figure 9. provides somewhat more useful information than does Figure 8. for generating hypotheses about the relationship between a particular farmed Atlantic salmon producing nation (Norway) and the reduction fish species which, historically, have supplied a large part of the fishmeal and fish oil demand of the producing firms in that nation. For example, it leads to the questions of whether the majority of the production of any of the three species shown in the graph, or perhaps the production of the three species summed, is consumed each year mainly by Norway's farmed Atlantic salmon operations; and, if so, whether the consumption of that volume of reduction fish constitutes the total consumption of the Norwegian farmed Atlantic salmon enterprises or whether additional volumes of reduction fish, embodied in fishmeal and fish oil, are obtained from elsewhere. Answers to these questions would help establish the true relationship between the output of the reduction fisheries for these species and the output of farmed Atlantic salmon in Norway.

Figure 9. Mix of major species in Norway's fishmeal/fish oil production



Unvalidated data (reported as "Trade Sources" in FIN, 2006) on sources of fishmeal used in aquaculture in the UK in 2004 indicate that about 50% of the fishmeal consumed was from sources outside the European Union (EU). Such sources include nearby but non-EU countries such as Norway as well as distant countries such as Peru and Chile. According to these data, fishmeal from Peru accounted for about 10% of the UK's consumption in 2004. Reliable trade and industry information could help resolve questions about the sourcing of fishmeal and fish oil for the major farmed Atlantic salmon producing countries, which would then enable better measurement of the amount of Peruvian natural capital appropriated by these other nations.

It is relevant to note also that fish used for reduction into fishmeal and fish oil come from three main sources: fish caught specifically for reduction (either a portion or all of the catch), such as the Peruvian anchovy and the sandeel; fish discards or trimmings from the processing of food fish; and by-catch, or undesired organisms caught in the process of catching target species (Naylor and Burke, 2005). Thus, in terms of both the source and the species composition, fishmeal and fish oil products originating from different countries but sold on the global market implicate different ecological and social impacts. Tracing the life-cycle ecological impacts of a particular quantity of fishmeal or fish oil is difficult, because most fishmeal and fish oil producers do not specify the precise mix of species that were used to constitute their products. Typically, only total protein content and other important nutritional or compositional information are provided. Species composition can be inferred from catch and fishmeal/fish oil production data, so long as the amount of the species composition and amount of the catch diverted for human consumption are known. Of total global landings of fish species destined for fishmeal and fish oil, FAO averages from 1997-2001 indicate that anchovy constitutes approximately 35% of the total; capelin, 6%; blue whiting, 4%; sandeel, 4%; and all other single identified species, such as herring and horse mackerel, 2% or less each. The same FAO data indicate that 45% of the total fish landings destined for fishmeal fall into an "other" category. Thus, the precise species composition of a large fraction of the world's fish being landed for fishmeal is either unknown or unreported.

2.4. Relevant contextual features of Peru

Any analysis of changes to the regional/local ecosystems upon which the people of Peru rely for the provision of foods, raw materials, and other ecosystem goods and services will need to take into account some basic features of population health, nutrition, socioeconomic conditions, and politics in Peru. The next section briefly considers, under four sub-headings, some important features of Peruvian society that need to be considered in the future development of specific hypotheses about nutrition-related population health impacts of the GFASI on the people of Peru. These features also affect the level of confidence we have in the accuracy of the propositional causal web illustrated in Figure 13.

2.4.1. Population health in Peru

Recent news reports and quantitative data show that a large proportion of Peruvians live in severe poverty and lack access to basic resources such as clean water and sanitation services (Emmott, 2006; UNDP, 2006). Currently, one in two Peruvians lives on an income below the level considered adequate to meet basic material needs, and roughly 15% live in extreme poverty (PAHO, 2006). One clear health risk of poverty is inadequate nutrition. According to the United Nations, widespread under-nutrition, linked to poverty and food insecurity, has been a major but diminishing cause of ill health in Peru. The UN Standing Committee on Nutrition reports that in 1990-1992, 40% of Peruvians were considered undernourished. This rate dropped to 18% in the period 1995-1997, and to 11% in 1999-2000 (United Nations, 2004). However, given the much higher proportion of the population that is deficient in some micronutrients, such as iron, under-nutrition figures should be treated with caution and likely underestimate the prevalence.

Inadequate food quantity or quality often manifests in growth and stature deficits in children. As an average of prevalences reported in the period 1996-2004, 25% of Peruvian children under five years of age suffered from moderate to severe stunting (height that is two or more standard deviations below the mean height for age). This compares with 14% in Colombia and Paraguay, 11% in Brazil, and only 2% in Chile (UNICEF, 2005). Again, as with other population health indicators, in Peru there are wide disparities in prevalence between departments (regions) and urban and rural locales.

The infant mortality rate (often used as an omnibus indicator of maternal nutritional status) in Peru is, at 24 deaths per one thousand live births, around the median of countries in the western hemisphere—but much greater than the rate in wealthier countries such as the United States (seven deaths per one thousand live births) and Canada (five deaths per one thousand live births) (UNICEF, 2005). The average infant mortality rate obscures major differences between the wealthiest and poorest Peruvians; the infant mortality rate in Peru is almost five times higher in the poorest quintile of the population than the uppermost quintile (Savedoff and Schultz, 2000).

While high rates of infection and death from communicable diseases, high or relatively high maternal mortality, and other indicators characteristic of societies yet to undergo the epidemiologic transition (Omran, 1971) continue to be serious problems in Peru, some kinds of chronic disease are on the rise. Rapid economic development and cultural change in urban centers in the country has paralleled an increase in diseases and risk factors associated with more affluent and sedentary societies--for example, diseases of the circulatory system and some types of cancer, and a higher prevalence of overweight and obesity. According to PAHO statistics reported in Huynens et al (2005), in 1972 only 5.6% of total deaths were attributable to malignancies, a proportion which grew to 14.2% in 1997. PAHO (1998) also reports that between 1968 and 1991, the frequency of breast cancer in Peruvian women increased while the frequency of cervical cancer declined. In Peruvian men during this period, the mortality rate from stomach declined and the mortality from prostate cancer increased. Growing income inequality in Peru, and a health care system currently ill-equipped to deal effectively with such a wide range of old, new, and re-emerging population health concerns, adds to the complex milieu of public health in Peru.

The disparities in basic nutritional status among regions of Peru suggest that investigations of the health impacts of food supply changes (such as changes in the quantity or quality of available fish, which is our interest in this study) should take into account regional differences and stratify data by important distinguishing features of the different regions (e.g., income, the rate of existing nutrition-related disorders, and per capita daily food intake) that are likely to affect the magnitude of the impact of changes in particular components of the food supply on nutritional health.

Investigation of the population health implications of changes in specific components of the Peruvian food supply need to recognize that for some subpopulations in Peru, risk factors related to over-nutrition are increasingly prevalent. Notably, the aggregate data indicate that the prevalence of adult Peruvians aged 20-74 years considered overweight was 55.4% in 2000. (The WHO and PAHO define overweight by reference to the Body Mass Index (BMI), which is calculated as an individual's mass in kilograms divided by the square of his/her height in meters. A BMI of 25 or greater indicates overweight.) More recent data, and historical data past 1996, were not obtained for this indicator, but data from 1996 and 1997 indicate prevalences of 40.1% and 33.4%, respectively (PAHO, 2001-2005). This is actually greater than the estimated prevalence of overweight in Canada (47.4%) in 2001, the only year for which PAHO data were available for that country (PAHO, 2001-2005). Uauy et al (2001) suggest that, especially in urban areas where access to modern processed foods is greater, poorer subpopulations tend to use incremental improvements in income to purchase high fat/high carbohydrate, energy-dense foods and reduce consumption of traditional grains, fruits, and vegetables.

Reliable Peruvian data on risk factors for disorders of over-nutrition, such as overweight and obesity, stratified by income level and by survey-based measures of dietary composition, could provide useful information for predicting the dietary impact of changes to the quantity or quality of fish available for consumption by Peruvians. Again, this reflects the logic that changes in the availability or quality of a particular type of food are likely to affect differentially the health of sub-populations (if they are affected at all), and be modified both by the resources available to the different sub-populations to obtain alternative, substitute foods and by the baseline importance of the specific food item in the diet. More specifically, it would be useful to have more knowledge about how dietary supplementation with high export-volume fish species such as anchovy (as has actually been promoted by the FAO and Peruvian government) would or would not improve health in each of the multiple subpopulations of Peruvians.

However, even for sub-populations where detailed data on dietary intake are available, it is difficult to know what change in total fish consumption, or in the quality of the fish being consumed, would lead to detectable population health impacts in those sub-populations. In our case study, it may be that “fish” simply encompasses too many types of nutritional factors and risks (e.g., protein, essential oils and fatty acids, industrial contaminants) for the level of fish consumption to be meaningfully related with specific health outcomes, even when other components of the target population’s diet are held constant.

2.4.2. Peruvian diet

Limited aggregate data are available on food consumption patterns in Peru (e.g., Bermudez and Tucker, 2003; FAO, 2000). The FAO (2006) indicates that North and South America rank lowest among world regions on the proportion of fish protein in the total average protein intake. However, variation is great among countries within these continents. Fish constitutes a higher proportion of the total protein supply in Peru than it does in other South American countries. In 2002, in Columbia, this proportion was only 2.3%; in Brazil it was 2.1%, and in Paraguay it was only 1.9%. That same year, fish accounted for 9.2% of the total protein supply in Peru (FAO, 2006). In Brazil, Colombia, and Peru, these proportions have remained quite stable over the past twenty years of data.

In absolute terms, the amount of protein derived from all fish sources is also greater in Peru than in other countries in the region. The FAO (2006) reports that in 2004, only 6.0g/day per capita of protein from fish were consumed in Peru. This compares with 1.4g/day in Colombia, 1.7g/day in Brazil, 3.3g/day in Chile, and 4.9g/day in Venezuela. For comparative purposes, values for the USA and Canada were 4.7g/day and 5.9g/day, respectively. Appendix 2. breaks down the above *per capita* per day fish protein consumption figures by category of fish; the disaggregated data are from FAO (2006) and were last accessed on February 9, 2007.

Although there are many possible reasons for the discrepancies between countries, the relevant issue for the development and investigation of hypotheses about the effect of changes in the quantity or quality of fish available for consumption by Peruvians is that a country deriving a greater proportion of its total protein from a single category of food (e.g., fish and fish products) may be at greater risk for nutrition-related health consequences associated with changes in that food category than would a country with a more diverse mix of protein sources. This is speculative, but follows the simple logic that a diverse diet would be affected less by the loss of any one element of that diet than would a diet consisting of fewer food types.

Table 6., adapted from FAO Peru Nutrition Profiles (2000), shows the relative importance, by percentage of total daily caloric intake, of various types of food in the Peruvian diet. This information was derived from household surveys, not food supply data (which, as noted, are often used as an estimate of actual consumption). The quality of these data was not available for examination.

Table 6. Food consumption in Peru by food category

Food Group	Approximate percentage of total calories consumed daily
Cereals (e.g., wheat, rice)	38.4
Sweeteners (e.g., sugar, honey)	13.7
Roots and tubers (e.g., potatoes)	12.8
Vegetables (e.g., squash)	7.0
Fruits (e.g., bananas, oranges)	6.6
Dairy products and eggs	4.5
Legumes and nuts	4.3
Meat (e.g., pork, beef, chicken)	4.1
Animal fats (non-dairy)	4.1
Fish and fish products	1.0
Other	3.5
TOTAL	100.0

Most relevant to the current study is the very low consumption of fish relative to the total mix of foods consumed by Peruvians, and despite the proportion of total protein obtained from fish being relatively high in Peru compared with other South American countries and even with Canada and the United States. These aggregate data need to be interpreted cautiously, since there may be sub-populations of Peruvians who eat much more fish than the average and for whom a large drop in the availability of fish would pose a significant dietary challenge, both from a caloric (energy) point of view and from a food quality (e.g., protein content) point of view. For those Peruvians who are obtaining only about 1% of their daily calories from fish, it is difficult to imagine there being any significant health outcomes from a drop in the quantity or quality of fish consumed, unless the total daily caloric intake were already inadequate or the fish in the diet were providing essential micronutrients found nowhere else in the diet. It would be instructive from economic and social perspectives to learn how the proportions that various food types represent in the total diet change when the intake of any one food type changes. It would also be useful to know if and how the proportion of fish in the Peruvian diet changes in years when anchovy production is low. Additionally, some foods which are roughly related by source (e.g., dairy and meat) may be expected to vary simultaneously if the root cause of that variation is ecological in nature.

A comparison of aggregate food supply data between the periods 1989-1991 and 1996-1998 shows that in terms of proportion of total dietary intake, consumption of animal products of all kinds has increased slightly, while consumption of vegetable products of all kinds has decreased slightly (FAO, 2000). It is unclear whether the difference is statistically significant for either food category, and also uncertain precisely how this difference is related to changes in the prevalence of nutrition-related disorders in the population. Many other shifts in food consumption patterns have taken place in Peru in the past few decades, such as a quite large increase in the consumption of sweeteners, and it should be noted once again that considerable variation exists in dietary quality and quantity between subgroups in Peru—especially between urban and rural residents and between residents of the Lima metropolitan area and the rest of Peru.

It is also significant for this study to stress that Peruvians directly consume only very small quantities of the Peruvian anchovy, the primary species reduced into fishmeal and fish oil in Peru. Data on actual consumption levels were not located. Anchovies generally are not considered palatable and are rarely used in quantity in modern cooking. In the past decade, both the FAO (2002) and the Peruvian government have attempted to increase domestic human consumption of anchovies. Approximately 10% of anchovies currently caught in Peruvian waters are processed for human consumption; we could not determine what proportion of that 10% is consumed outside of Peru. The Peruvian government is seeking to increase the proportion of anchovies processed for human consumption to 20% or even 30% of the catch, according to one unpublished government source, but no data were found to suggest that the amount of anchovies in the Peruvian diet has been increasing in recent years. The FAO (2003) indicates an increase in domestic sales of all fish for 2001 compared to the previous year, but it is unclear whether any of that change is accounted for by increased anchovy consumption.

Most of the fresh and frozen marine fish consumed directly by humans in Peru are demersal, white-fleshed species such as hake. If changes in fish quantity or quality directly result from ecological changes caused by the Peruvian anchovy fishery as it is influenced by demand for fishmeal and fish oil by the GFASI, these changes are likely to be felt only if the quantity and/or quality of these domestic demersal fish species are reduced, or if the Peruvian anchovy fishery somehow contributes to ecological changes that affect the quantity and/or quality of the fish and fish products being imported into Peru. Figure 10. below shows the fluctuation in *per capita* annual fish supply (consumption) by Peruvians in the period of the GFASI's operation, based on data from the FAO (2006). These data do not show any sustained upward or downward trend in this time period.

Figure 10. *Per capita* supply of fish, Peru (1970-2002)

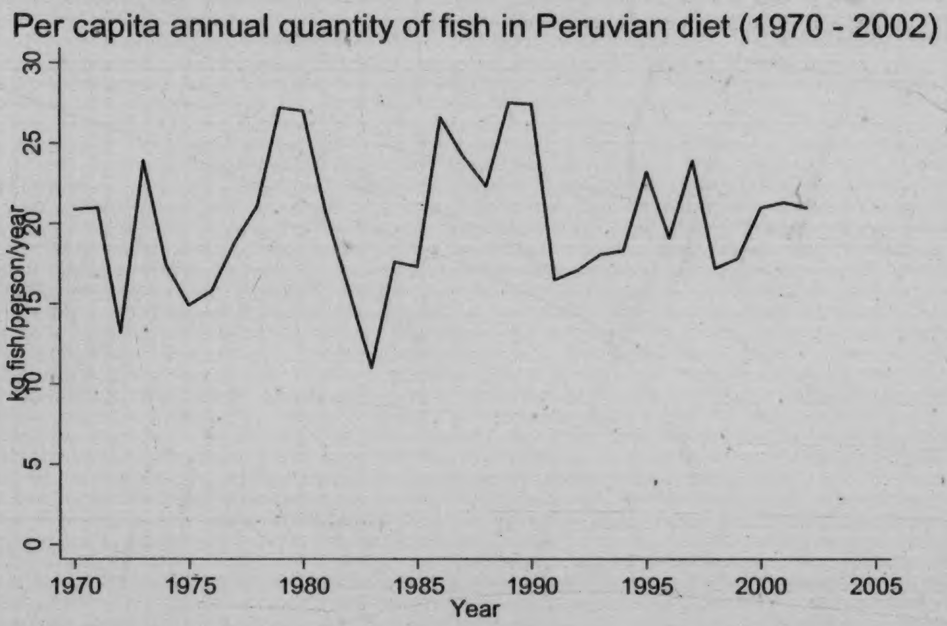
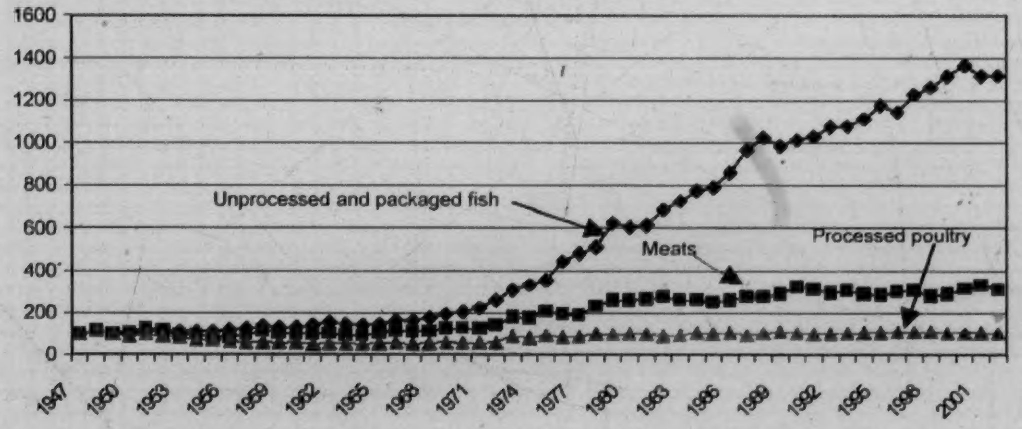


Figure 11. below is excerpted from Bermudez and Tucker (2003). The caption connected with the original graphic (i.e., "Figure 1.3.") should be ignored.

Figure 11. Prices of fresh and processed fish compared to meats and poultry (USA)

Figure 1.3 Prices of fresh and processed fish compared to meats and poultry



Source: U.S. Bureau of Labor Statistics. U.S. Producer Prices, deflated by U.S. Producer Price Index, 1947 = 100.

A similar graphical representation of the prices of meats and poultry compared to fish could not be obtained for Peru, but data of this type would be useful for better determining the micro-economic features of protein consumption in the aggregate Peruvian population and in various culturally and socio-economically distinct sub-populations. Figure 11. above shows the increase in the price of fish compared to meats (beef, pork) and poultry from the mid-1970s to nearly the present. Despite this price increase, or as a cause of it, the fish supply *per capita* (a proxy for fish consumption) in the US actually rose from 14.7 kg per year in 1970 to 21.3 kg per year in 2002 (FAO, 2006). We did not determine the reasons for this increase. Meat consumption in the US also rose during that period, from 105.9 kg *per capita* in 1970 to 124.8 kg *per capita* in 2002 (FAO,2006). That meat prices remained constant while fish prices rose dramatically during this period, and that this occurred while consumption of both commodities increased, provides information on features of the demand for these products. Again, similar information for Peru would be helpful for better understanding the role that household income plays in levels of fish consumption in Peru, although with the caution that other factors, such as a popular move towards food choices perceived as more healthy, also may be involved.

2.4.3. Socioeconomic conditions in Peru

On a *per capita* basis, income in Peru is much lower than in countries such as Canada and the United States (World Bank, 2006); because food prices are not proportionally lower than they are in countries like Canada and the United States, Peruvians must spend a larger proportion of their incomes on food in order to meet basic daily food needs. This implies that an increase in the price of a particular food may induce substitution more quickly than it would in a country where the average income is higher. In economic terms, the cross-price elasticities of demand for food products are likely different for those with less versus more income. This needs to be taken into account when projecting the impact of price changes for items such as fish which may increase in price if supply is reduced. For the small minority of Peruvians who mainly eat fish caught directly by themselves, a family member, or someone in their community, the effect of a price change in fish would be a different matter, and would likely be a function of the share of those persons' total fish consumption that is purchased (versus caught directly or farmed).

Given that the Peruvian anchovy fishery has experienced dramatic downturns (for example, the anchovy population crash in the early 1970s) another socioeconomic mechanism of effect on population health, should the anchovy fishery be reduced in size, would operate through the loss of employment and income. It is estimated that more than 100,000 persons in Peru are employed in fishing, fish processing, and related activities associated with fishing and fish processing (FAO, 2003). Important changes to the Peruvian fishing industry in the past, sometimes only indirectly associated with ecological change, have resulted in substantial swings in employment rates in the industry (Ibarra et al, 2000). For example, in the years immediately following the government's decision in 1973 to place the industry under state control, in an attempt to better contain the risk of overfishing, the number of fishmeal and fish oil processing plants dropped from 99 to 37. Well-established links between employment status, income, and health (e.g., Stronks et al, 1997) suggest that the impact on fishing jobs and income of regional/local scale ecological changes, such as crashes in fish populations, are likely significant pathways by which population health is affected.

2.4.4. Governance in Peru

Since the initial industrialization of the Peruvian anchovy fishery just prior to World War II, many changes in fisheries management and regulation have affected the anchovy fishery and other fisheries in Peru. Internal politics, and international pressures impacting internal politics in Peru, have been profoundly influential on the total size of the Peruvian fishing industry, the allocation of resources to fishing for particular species and to processing the catch, management and conservation of fish stocks, and export-oriented versus domestic marketing of Peruvian fish products. As with other contextual features discussed above, usefully investigating the effect of the GFASI on the anchovy fishery in Peru, and, via that fishery, on ecologically-mediated population health in Peru, requires due consideration of political factors that have the potential to modify relationships at many points in the causal web presented as Figure 13. These factors include the rules and regulations of international trade and domestic economic development priorities.

2.5. Literature review and background to development of the accounting framework

2.5.1. Introduction

Material was provided in Chapter 1 on global ecological change and human health. In Chapter 2, the discussion focused on the global farmed Atlantic salmon industry and on some of the contextual features of Peru that are relevant to the impact of the GFASI in that country. Sections 2.5.2. through 2.5.8. below introduce the idea of, and some of the theoretical and practical issues involved with an accounting framework for guiding the assessment of ecologically-mediated population health impacts caused by global-scale industries such as the GFASI. Development of such a framework is a logical complement to the exploration of specific case studies of the links between global-scale industries (such as the GFASI) and ecologically-mediated population health impacts, because we often do not know where to direct our research attention, nor how to interpret research findings, nor how to translate what is discovered in the eco-health realm into language relevant to policy makers. Thus, guidelines are needed. The accounting framework approach introduced below, and developed further in Chapter 5, aims at enabling more critical and structured evaluations of global-scale industries as powerful influences on human health through their impacts on ecological conditions.

2.5.2. Purpose of the accounting framework

The purpose of the accounting framework is to guide and structure the assessment of the ecologically-mediated population health gains and losses associated with global industries.

In particular, the accounting framework developed in this study attempts to guide the investigator, for any particular global industry, to account more carefully for (1) the population health impacts associated with the productive and waste assimilative capacity of the ecological "stocks" upon which each industry depends; (2) the population health impacts related to the global and regional/local scale ecological changes caused by the regular "flows" of energy and materials through that industry; and (3) the population health risks generated by loss of the power of EI to buffer human populations from natural or human-caused events. Population health impacts flowing from ecological changes are likely to be realized at the regional/local scale; however, the drivers of those regional/local level ecological changes may be global in scale (e.g., global warming, changes in major ocean currents) or regional/local in scale (e.g., a significant change in the biodiversity of a specific ecosystem).

2.5.3. Other accounting schemes for measuring the impacts of industrial activity

There are numerous accounting schemes for measuring different features of human production and consumption activities. For example, the widely used Gross Domestic Product (GDP) measures, in a defined currency, the total market value of the goods and services produced within a country's borders (i.e., domestically) in a given period, after deducting certain types of production costs to avoid double-counting. In the calculation of the GDP, there are rules for including some activities and not others in the accounting, estimation procedures for situations where data on precise monetary values are lacking, and ways of dealing with uncertainty. Transparency in the background assumptions and calculation process for the GDP calculus facilitates critique and revision of this particular accounting system. Because the GDP only considers the flows of money in the economy (and not, for example, the ecological sustainability of the activities that channel those flows of money, the distribution of the money in the population, or the social and public health implications of expenditures), it is regularly criticized for its use as a measure of economic well-being (Cohn, 2006).

Indicators of economic or social health reflect, by what they measure, underlying value judgments about what is important in society. For example, the GDP's focus on the market value of the goods and services produced in a country suggests that the volume of money moving between actors in the formal economy is important, and that this volume is a marker of economic, and hence of social, well-being. That the GDP is a very widely accessible statistic is a sign of the underlying judgment that has been made about the meaningfulness of the GDP as a measure of economic well-being. However, it also reflects the historical neglect of social and environmental costs in national accounting. Many of these costs are very difficult to quantify, and consensus on approaches to quantification has been absent. Of course, as with summary measures such as the EF in the ecological domain, in the economic domain no single summary measure could ever provide more than a crude overall view of what it aims to measure or indicate.

The Ecological Footprint (EF), discussed in section 1.7. and calculated for the 2004 production of the GFASI in section 5.4., provides another example of a measure that has become increasingly transparent about its assumptions and internal calculations, thus facilitating its further refinement. Since its original conceptualization, EFA has refined its methods for determining the extent of an entity's ecological impacts; its means for addressing uncertainty related to existing knowledge about ecological states and dynamics, relevant causal relationships, and the validity and power of the methods of analysis; and its assumptions relevant to the interpretation of results.

GDP and GNP, as the most widely used gross measures of economic "health" or progress, do not account for the size of the EF of the nation in question, just as the various (traditional) financial statements of the companies that make up the GFASI do not account for the size of their individual contributions to the EF of the entire industry. By extension, these traditional statements also do not account for the population health impacts which may be associated either with an EF for the industry of a particular size or with the specific ecological impacts (such as the distal impacts which have been the focus of this study) which might be determined by disaggregating the EF. As it is, then, the most data-intensive basis for making decisions about the future operation of the GFASI is the flow of money through the industry. Fisheries and Oceans Canada speaks of all Canadian aquaculture enterprises (which include farmed Atlantic salmon operations) in very positive terms: "The [aquaculture] industry has responded to a global demand for fish and seafood by providing a nutritious and affordable source of protein," and "The [aquaculture] industry offers many economic benefits for Canadians living in rural, coastal and Aboriginal communities (Fisheries and Oceans Canada, 2006)." Such comments may be because the most reliable information on the industry is its financial performance, exclusive of data on social and environmental costs and liabilities.

Alternative measures of progress and social well-being, such as the Genuine Progress Indicator (GPI), have been developed that aim at better describing and measuring more of the things that constitute a healthy society, including ecological health and some of the important non-monetary and qualitative features of the economy, such as unpaid work and time and energy spent caring for children or participating in community activities. The GPI attempts to measure the quality and distribution of economic growth, not simply its size in pure dollar terms (Redefining Progress, 1998). McMurtry (2002) mentions several other quality-of-life indicators that have been developed at least at an elementary level in recent years. These include the United Nations Human Development Index (HDI), the Index of Social Health (ISH), and the Statistics Canada System of Environmental and Resources Accounts. Although these indicators are an improvement over ecologically blind measures such as the GNP and GDP, according to McMurtry they still fail to account for all of the fundamental "life coordinates" that indicate the well-being of a society; none of the following eight elements can be diminished without reduction of vital life capability:

1. Air quality
2. Access to clean water
3. Sufficient nourishing food
4. Security of habitable housing
5. Opportunity to perform meaningful service or work of value to others
6. Available learning opportunity to the level of qualification
7. Healthcare when ill
8. Temporally and physically available healthy environmental space for leisure, social interaction, and recreation

From the standpoint of overall health impact, the ideal accounting for a global industry such as the GFASI would include a measure of its impact on each of McMurtry's eight factors, at all relevant time scales and in all societies where these impacts occur. Methods for measuring industry impacts on these factors would have to be developed, and the undertaking could be enormous in scope. Also, it is well beyond the purview of this study. For the overview of the development of the accounting framework provided in this study, the Genuine Progress Indicator's attention to both flows and stocks of natural assets (Anielski and Soskolne, 2002; Hamilton, 1999) is relevant. This fits conceptually with the approach taken in the GFASI case study, in which the sustainability of the industry was estimated based on its EF (a reference to the total "stock" of Earth's bioproductive capacity), and the impacts of one of the important "flows" of resources in the industry, the flow of anchovies into farmed Atlantic salmon production, were considered. The GPI's attention to both flows and stocks is based on the ecological law that there is a limit to the consumption level in any given year (something short of all that could be consumed), because the stocks that supply the flow of the goods and services consumed must be replenished. Consumption above the level that can be sustained not only reduces the volume of the flows, but potentially degrades the stocks in such a way that future flows also are diminished. Moreover, the integrity and thus the biocapacity of the whole ecosystem must be protected to ensure sustainability of the energy conversion processes, nutrient and chemical cycles, and other ecosystem services that support both natural capital stocks and flows. The GPI attempts to account for several elements of societal well-being not addressed by the accounting framework developed in this study. However, linking specific population health impacts to specific ecological states, and interpreting those links, would be left to the analyst. The GPI is useful but not wholly suitable as a template for the accounting framework developed in this study.

The accounting framework developed here focuses only on population health impacts and risks related directly to changes in ecological conditions (such as a reduction in a specific ecosystem good, like a fish species consumed by humans). As some prior research (e.g., Sieswerda et al, 2001; Huynens et al, 2004) has shown, the relationship at the national level between conventional aggregate indicators of population health, such as life expectancy or health-adjusted life expectancy, and ecological conditions, is uncertain and almost certainly confounded or modified by monetary wealth. As stated earlier, this uncertainty is believed to be related to the way in which, via global trade and foreign-owned production, the accounting for money-generating economic activity is disconnected spatially from the ecological impacts of that activity. However, the population health indicators used in these studies also may be insensitive, at relevant time scales, to changes in the ecological integrity parameters. Future research needs to address this question by testing other potentially sensitive indicators (e.g., rates of specific diseases, such as vector-borne diseases which can be sensitive to changes in land disturbance) and developing new indicators.

The accounting framework introduced in this section, and developed further in Chapter 5, attempts to deal with the problem of international trade by directing the researcher to locate and describe the actual ecosystem impacts associated with industrial activities (such as changes in the flows of specific goods and services that support population health in the regions of concern)—not just the aggregate demand of the industry on biocapacity. It also attempts to show how to think through the question of what any particular global industry's ecological impacts mean for human population health, wherever and whenever those impacts occur. It assumes that the population health of a society or of the human community can sometimes be meaningfully indicated by gross measures such as life expectancy, which reflect multiple conditions and exposure levels in populations, but also by indicators of specific disorders, diseases, or risk factors that affect the quality of life and the potential for community development. These problems may be concerns such as nutritional deficiencies or rates of birth defects from maternal exposure to chemicals during pregnancy.

2.5.4. Key questions that must be addressed in an accounting framework

Four key questions are identified to provide transparency in an itemized accounting framework for assessing ecologically-based population health impacts stemming from specific global industries. An accounting framework that is transparent will permit critique and thus be credible and open to revision and refinement. The four questions are:

(1) By what method(s) will the identity of an industry's known or potential ecological impacts be determined, and according to what criteria will those impacts be included in the accounting framework?

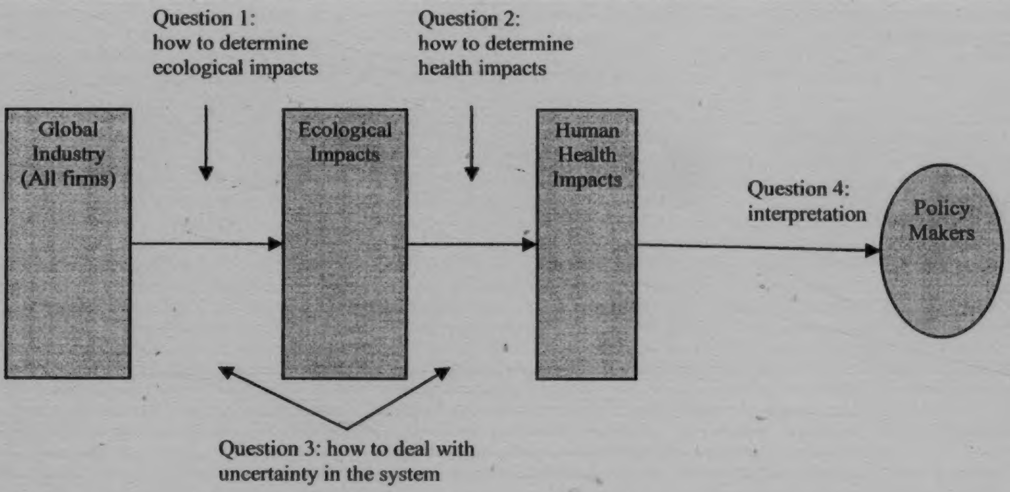
(2) How will the subsequent determination of known or potential population health harms and benefits from ecological impacts in (1) be made, and on what basis for inclusion in the accounting framework?

(3) How will uncertainty be addressed in (1) and (2) above, relating to existing knowledge of ecological and population health states and trends, causal relationships, and the validity and power of the methods of analysis?

(4) How will the characteristic features—in time, in space, and in strength of association with putative ecological cause(s)—of the population health harms and benefits be interpreted within the accounting framework so that policy-makers might better understand: (1) the ecologically-mediated costs to human health and well-being from industrial business-as-usual (BAU) modalities over multiple time scales; and (2) the changes to those industrial BAU modalities that would be required to reduce the ecologically-mediated costs to human health and well-being over these same time scales?

Figure 12. below provides a skeletal schematic of the accounting framework in light of the structure suggested by Questions 1-4. A more fully developed schematic of the framework is provided in Figure 18. in Chapter 5.

Figure 12. Structure of accounting framework as suggested by Questions 1-4.


Question 1:
how to determine
ecological impacts
Question 2:
how to determine
health impacts
Global Industry (All firms)
Ecological Impacts
Human Health Impacts
Question 4:
interpretation
Policy Makers
Question 3: how to deal with
uncertainty in the system

Questions 1-4 will be addressed individually in Chapter 5. Sections 2.5.5. through 2.5.8., below, discuss relevant conceptual issues as well as some further features of the economic and ecological worlds in which global-scale industries operate.

2.5.5. Industry outputs

Industries do not simply produce population health benefits and harms as byproducts of their operations; they also produce their intended goods and services. Regardless of the actual output of an industry (e.g., blueberries, legal services, or weapons of mass destruction), or its ecological or population health impacts, traditionally that industry is deemed “good” for society simply if its economic activity contributes to the growth of the gross domestic product (GDP). Since GDP and basic measures of population health are strongly correlated at the country level (Sieswerda et al, 2001), growing the GDP has been affirmed by World Bank officials as a key means of improving national population health (Pritchett and Summers, 1993). However, as we have seen, the ecological costs of securing gains in population health are not necessarily borne by the country that receives the gains. Further, human activities that increase total entropy in the ecosphere may result in population health benefits at some time scales, but contribute to major population health harms in the long term if the foundational provisioning functions of the ecosphere are undermined.

2.5.6. The concept of a balance sheet in relation to the accounting framework

The techniques of modern accounting, including the process of balancing accounts, have their origins in the idea that at the macro-level the cosmos is a closed system: a withdrawal (or debit) here must equal an input (or credit) there, and *vice versa*. A revenue must be matched with a cost. The implications for financial accounting of this notion of cosmic harmony can be traced to the Italian Luca Pacioli (1445 – 1514), a Franciscan friar and contemporary and teacher of Leonardo da Vinci (Anielski, 2007). Although some techniques have changed, the basic principles of Pacioli's double-entry bookkeeping persist, as has the important principle that a loss of money here means a gain of money elsewhere. With some cautions, the concept of the balance sheet is useful for thinking about population health benefits and harms (or risks) associated with ecological changes caused by global industries. Gains in population health associated with increased monetary wealth in a population may be associated with losses of ecological stocks or EI, or changes in the flows of ecosystem goods and services, in places distant from the benefiting population. In theory, an accounting framework could guide the "balancing" of population health gains and losses if the relationships between money and population health, and ecological impacts and population health, were well known. Such information would then provide a basis for evaluating the equity and social desirability of the full suite of population health impacts associated with a particular enterprise. The accounting framework developed further in Chapter 5 will not focus on the population health impacts associated with the generation of monetary wealth, however, and is intended only as a guide to the identification of population health change stemming from ecological impacts.

There are other reasons why an accounting framework for assessing the ecologically-mediated population health impacts of global industries cannot be a simple extension of the classical accounting process of balancing accounts. Important among these reasons is that the population health benefits and harms that we wish to determine and measure are for the most part negative and positive externalities of the industry being assessed—not the goods, services, or financials about which the industry already has knowledge. For example, the GFASI produces farmed Atlantic salmon, and the industry's accounting statements will show assets such as salmon grow-out infrastructure, costs such as the cost of feed material, and shareholder's equity such as invested company profits. However, the ecological externalities in which we are interested are the ones that do not find their way into conventional financial statements: the multi-scale ecological costs of the operation of the industry and the population health benefits and population health harms associated with those impacts. The objective which the accounting framework aims to help meet is that of identifying these externalities and internalizing them, in population health terms meaningful for policy makers, in the relevant global industry. The end result would be a disaggregated and detailed list of the various population health impacts associated with the ecological impacts attributable to the industry being assessed. These impacts could then be considered in light of the negative and positive population health impacts from other consequences of the industry (such as providing employment) in order to obtain a profile of the industry's total impact on human health. Provided that those changes in ecological conditions to which elements of population health are sensitive (as well as those elements of population health themselves) can be quantified, "ecological" cost-effectiveness analyses could be conducted. Being able to compare more and less ecologically efficient means of achieving a certain change in population health (such as the increase of a beneficial feature or the decrease of a harmful feature) could inform policy development. Further development of the technical aspects of conducting ecological cost-effectiveness analyses is not attempted in this study, although the accounting framework developed further in Chapter 5 aims to elicit the data and information needed for such analyses.

Many industries produce a good which can be purchased for different end uses, and the use to which that good is put may alter its ecological and population health impacts. This means that two or more assessments could be produced for a given industry, or alternatively that a single assessment would account for the proportion of product going to each of the two or more end uses, each of which may have its own unique profile of ecological and population health impacts. The value of this complication is that it could enable a comparison of end-uses in terms of their ecological and population health impacts. Fishmeal provides an example. The ecological and human health implications of fishmeal production on the front-end (i.e., the impacts of the reduction fisheries and the fishmeal and fish oil processing plants) would be the same regardless of the end-market for the fishmeal. However, the life-cycle ecological and human health implications of the fishmeal would be different depending on whether the fishmeal was used in the production of farmed Atlantic salmon or farmed shrimp, as a constituent of pig or poultry feed, or as a component of fertilizer.

Research continues into ways to assign economic value to ecosystem goods and services, and the costs to human beings of reductions in the capacity of the ecosphere to produce those goods and services (e.g., Costanza et al, 1997). As Anielski and Soskolne (2002) note, numerous researchers and organizations have recognized the possible human health consequences of declining global EI. Attempts also have been made to determine relationships between indicators of ecological decline and basic indicators of human population health at the country level (such as the work of Sieswerda et al, 2001), and there are examples of work which has been done to clarify the relationship between the degradation of specific ecosystems and impacts on populations that depend on the provisioning function of those specific ecosystems (e.g., Confalioneri, 2000). These are promising signs that methods relevant to an accounting framework are available or are becoming available.

As Huynens et al (2006) note, however, it is still unclear which ecosystem functions are most important to sustain human health. McMurtry's list of eight life coordinates (see section 2.4.3) is a useful starting point for assessing the performance of a human economic enterprise in terms of its contribution to health and well-being; however, it is not clear which ecosystems in which locations are essential to ensure that those coordinates for a particular population are sustained at an adequate level. This means that considerable uncertainty attends efforts to state with precision which population health risks and benefits have increased or decreased as a result of which ecological changes, and which industrial actors have caused which ecological impacts. The exploration of the GFASI in this study provides evidence of this uncertainty. Our review of the literature related to the GFASI shows that no attempt has been made to determine the ecologically-mediated health risks and benefits associated with the operation of that industry on a global scale. However, concerns have been raised about the regional ecological deterioration and environmental pollution caused by farmed Pacific and farmed Atlantic salmon grow-out operations, as noted earlier (e.g., Georgia Strait Alliance, 2006) and the consequences to regional food supplies of converting small pelagic fish into fishmeal and fish oil for the production (and consumption) of farmed salmon in wealthy nations (Naylor et al, 2000).

The case study exploration of the GFASI showed that ecological impacts caused by the industry, or to which the industry contributes in concert with other industries and natural phenomena, occur over multiple spatial and temporal scales. Assessing the population health impacts of these ecological changes also then must involve assessment at multiple spatial and temporal scales. Financial accounting typically discounts the value of benefits and costs expected to be realized or borne in the future, and it does not discriminate among the populations or persons who will reap/bear those benefits and costs. In light of the public health ethics of autonomy and equity, including inter-generational equity, and given the realities of global trade whereby ecological and population health impacts can occur at great distance from the primary point(s) of monetary wealth consolidation, conventional accounting processes provide useful concepts but require adaptation.

2.5.7. Ecological flows and stocks

Accounting for the ecological impacts of industry requires attention to both ecological flows and stocks. As with other ways of categorizing the benefits that humans receive from the ecosphere, "stocks" and "flows" are not always distinct categories. For example, ecosystem goods and services which are renewed regularly are usually considered flows--examples are the annual crop of fruit on a tree and the annual recruitment of fish into that stock which is designated suitable for catching. Stocks are the ecological functions or substrates requisite for the regular production of flows—examples are nutrient cycles and healthy soils, but also adequate populations of actively reproducing fish and adequate populations of plant species and their pollinators to ensure the generation of new plants and harvestable plant parts.

The terms "stocks" and "flows" are perhaps more germane to the concept of an "accounting" framework than are the terms (ecological) "goods and services," which would include less tangible benefits such as nutrient cycling. However, the further development of the accounting framework described in Chapter 5 will generally use the terms "goods and services," as it is implied that an assessment of the impacts on ecosystem goods and services by a global industry would take into account not only the annual loss in the flow resources (e.g., catchable fish), but also any degradation of the stock (e.g., the reproducing adult fish population and the conditions that sustain that population) that would influence the level of these flow resources over time. Also, the need to measure benefits such as nutrient cycling must be recognized even if rigorous measurement methods are not yet available.

2.5.8. Importance of context to assessments of population health impacts and ecological impacts

The associated population health impacts of the appropriation of ecological goods and services by global industries are expected to be specific to context. The baseline health statuses of the populations affected by the ecological impacts are perhaps the most salient contextual features. The loss of a local source of high-quality protein, for example, may be more devastating to a population already suffering protein deficiencies than for a population already consuming protein in excess. The importance of various contextual features in the assessment of population health impacts suggests the value of requiring a thorough initial case study as part of the accounting process.

Another important contextual issue, relevant both to the accounting process and to the interpretation of the results of that process, is the issue of how a given industry is situated in relation to other contributors to ecological change. For example, assessing the ecological sustainability of a single industry such as the GFASI requires some knowledge of the impacts of other industries that may be stressing the same ecosystems. An industry could damage a regional/local ecosystem so severely that it takes geologic time to recover, and this would indicate lack of sustainability at the regional/local scale. However, if that industry could appropriate resources from another ecosystem, it is possible that that industry could transport the needed resources from that ecosystem to the original site, or move to the new site and transport the products to consumers at the original location. If the supply of ecological goods and services were larger and more consistent in the "new" ecosystem, it is possible that the industry could, in ecological terms, sustainably produce the goods or services at the level that it could not produce them in the less ecologically productive region. If, however, there were no sufficiently productive and unclaimed ecosystems available anywhere on Earth, the industry would be unsustainable in the global sense. As Rees (2006) has suggested, the efficiency of global trade permits the continued operation of regionally unsustainable industries by making available ecosystem goods and services located all over the planet should an industry be able to buy those goods and services or coerce their relinquishment from the current stewards. Critical to the substantiation of any of this theory, however, is the question of measurement; whatever the location of the ecological impacts, we need to be able to measure whether the appropriation of specific ecosystem goods or services is, in fact, leading to losses in ecosystem integrity—i.e., the capacity of the ecosystem to continue to provide these benefits without incremental or dramatic quantity or quality losses.

With respect to how human population health benefits and harms (or risks) might be partitioned in the accounting framework, it will be important to distinguish between changes to ecosystem goods and services that have effects on the health of populations living in the region(s) of those changes, and contributions of the industry to population health impacts mediated by ecological changes that are effected by global scale processes (like global warming) to which the industry contributes. Taking the GFASI as an example, the former might include the regional population health impacts of a major change in the Humboldt Current Upwelling Ecosystem's (HCUE's) productivity caused by depleting stocks of anchovies and other small pelagic fish, while the latter might include the spatially dispersed population health impacts associated with the GFASI's contribution to global climate warming in concert with all the other industries of the world.

As an extension of these introductory sections and taking into account the issues raised therein, the broad outlines of an accounting framework are developed in Chapter 5.

Chapter 3. Study Rationale, Outline, and Objectives

"The leading contributions of ecology and health to our well-being lie in cementing the linkages between temporally and spatially removed hazards and their indirect health effects." (Parkes et al, 2003.)

3.1. Outline of this chapter

This chapter begins with a rationale for the approach taken in the present study. Following is a discussion of why the global farmed Atlantic salmon industry was selected as a case study, and lastly we present the three major objectives of our research.

3.2. Rationale and outline

Research into the ecological and human health connections between consumption in wealthy nations with relatively good population health, and resource extraction and/or processing in poorer countries with relatively poorer population health, is fundamentally concerned with the distributional justice ethic in public health: risks should not be borne by those populations who will not reap the benefits associated with those risks, unless the risk-bearers freely choose to accept the risks in light of accurate information about the links between the risks and benefits, including the distribution of the risks and benefits in affected populations at relevant time scales. The current study is an effort to encourage epidemiologists to find ways to come to terms with the complex multi-scale context in which exposures and health risks associated with ecological change increasingly are being generated.

Because of the limited usefulness of country-level, aggregate data in clarifying how the spatial and temporal disconnect between consumption and consequences (i.e., "the buffering phenomenon") obscures the relationship between ecological integrity and human health, this study considers the questions and concerns that would need to be addressed in order to evaluate, for a particular industry, the accuracy of a propositional web of relationships. This web leads from acts of consumption through changes in the ability of ecosystems to provide life and health-supporting goods and services, to distal population health impacts. Specifically, this study will explore many of the semantic, theoretical, and other issues that need to be resolved in order to address the research question of whether (and if so, how) the global farmed Atlantic salmon industry is causing ecologically-mediated population health impacts in Peru via demands made by the industry on the anchovy fishery of that country, as well as by contributions to other ecological change processes occurring at larger scales. This research question is expanded in the form of a research proposition in section 4.4.

This investigation will bypass some of the interpretive difficulties that arise when testing for associations between ecological and human health using aggregate data at the nation-state level, but as a primarily descriptive study it can only suggest hypotheses for testing in future research. Findings from the case study will suggest research hypotheses, and will also suggest the types of data needed, and some of the challenges that must be addressed, to test those hypotheses. To guide the investigation of the ecologically-mediated human health impacts of other global industries, an accounting framework will be developed. The accounting framework is proposed as a means to help guide the determination and evaluation of the population health impacts associated with the multi-scale ecological impacts caused by specific industries. Challenging issues in the development of the accounting framework will also highlight important theoretical and practical concerns in the emerging field of eco-epidemiology.

3.3. Why the global farmed Atlantic salmon industry as a case study?

Various possible case studies of international or global industries were considered as the focus for this study. All of these options hold potential for shedding light on certain features of the ecology-human health relationships that are driven by global trade. The banana industry in Costa Rica was the most seriously considered case study option among those options which were rejected. The global banana industry study was attractive because of some preliminary work which had been done to identify ecological impacts of the industry (e.g., Ferguson, 2002). Additionally, the banana industry includes both Fair Trade certified and organic alternatives to conventional modes of production, either of which could provide a control or reference point for comparison of impacts

(Murray and Raynolds, 2000). The banana industry has a complex and highly politicized history and it continues to contribute a large share of the total export-oriented agricultural output of some countries such as Ecuador and Costa Rica (Schor, 2005). The large scale of the industry and the value of keeping accurate data suggest that such data would be available—this also made it an attractive focus. As a case study, however, the GFASI was comparatively more attractive from an eco-epidemiological perspective, mainly because it directly implicates the bioproductive capacity of the world's oceans, which are not nearly as well demarcated politically as Earth's terrestrial land areas.

The global farmed Atlantic salmon industry was chosen for several reasons. First, in 2000 an EF was calculated for the industry as it was then operating in British Columbia, Canada (Tyedmers, 2000). A growing body of research on the (un)sustainability of global fisheries also exists (e.g., Pauly et al 2003, 2002; Pauly and Christensen, 1995; Myers and Worm, 2003; Naylor, 1998), suggesting the importance of work in this area. Some assert that aquaculture presents a "solution" to the global human population's protein needs, though rarely does this advocacy fail to discriminate between high-input, intensive, and inefficient forms of aquaculture and the opposite. There are some pointers therefore that indicate the value of exploring the global farmed Atlantic salmon industry's ecologically-related human health impacts.

Because wild salmon are still fished, a natural (imperfect) reference industry is already in place, which would permit a comparison of ecological and/or health impacts of interest. Other features of salmon farming open up questions about the micro and macro issues of health and wellness in our culture; for example, in terms of individual dietary choices, fish—and especially salmon—are perceived as nutritious and a good source of heart healthy Omega-3 fatty acids, although one study showed that fish are more readily identified as sources of harmful substances such as mercury (Verbeke et al, 2004). It is uncertain, however, what consumers of fish understand about the long-term ecological implications of enterprises such as salmon farming, and none of us know precisely what the human health impacts will be which are associated with the ecological changes wrought by these industries.

The farmed Atlantic salmon industry is truly global: consumption and/or production of farmed Atlantic salmon and/or production of inputs (such as fishmeal) to farmed Atlantic salmon production, take place on every continent. It is also a relatively new industry, it is currently large in economic and material terms, and it has expanded rapidly in the past 20 years. As such, the ecological and/or health impacts of the industry may be readily detected, and it is investigated in this study as a promising "window" through which to explore the ecological implications of particular modern-day enterprises that may impact on human health at various temporal and spatial scales through multiple causal pathways.

3.4. Objectives

The primary objectives of this study are two: (1) to employ eco-epidemiological concepts and methods (as noted in Table 1) to explore the merits of the proposition that certain nutrition-related disorders in a specific population have become more or less prevalent as a result of ecological changes caused by the global farmed Atlantic salmon industry (GFASI); and (2) to use information gained from the pursuit of objective (1), plus eco-epidemiological theory and knowledge from prior research in related areas, to develop an accounting framework for identifying the population health impacts associated with ecological changes initiated or exacerbated by the operation of defined global-scale economic enterprises. Specific objectives of this study are to:

1. Describe basic features of the global farmed Atlantic salmon industry (GFASI), with special attention to the ecological impacts of the GFASI that are either global in scale (e.g., contribution to climate change processes) or that occur in, near, or overlapping the political boundaries or areas of the domestic economic activity (e.g., fishing grounds) of Peru. The description of the GFASI will include:

    i.) A broad overview of the historical features of the industry as well as what characterizes it currently (done in Chapter 2);

ii.) A fictional narrative showing how a single act of consuming a serving of farmed Atlantic salmon might issue in an extensive array of ecological impacts (done in Chapter 2);

iii.) the propositional causal web through which individual acts of consumption of farmed Atlantic salmon culminate in health harms or benefits for Peruvians (presented in Chapter 4);

iv.) Discussion of historical, ecological, and socio-political features of Peru's anchovy fishery (presented in Chapter 5);

v.) Discussion of variables likely relevant in the causal pathway by which consumer demand for farmed Atlantic salmon culminates in population health impacts in Peru (presented in Chapter 5); and

vi.) Calculation and interpretation of an aggregate EF for the GFASI (presented in Chapter 5).

2. Use information obtained in the accomplishment of Objective (1.), as well as other sources, to lay the foundation for an accounting framework for the identification of ecologically-mediated population health impacts associated with global-scale industries.

3. Make recommendations for further research.

Chapter 4. Methods

4.1. Outline of this chapter

This chapter begins by discussing the case study design and the particular way in which it was approached in this study. Each term in the "GFASI" acronym is then defined, and limitations on the case study are reviewed. The approach taken to the literature review is subsequently defined; data sources and data quality issues are discussed; and the central research proposition is stated. A schematic diagram of the research proposition is then presented, along with definitions of key terms in that proposition. We then present a table of variables considered in this study and briefly discuss the ways in which the various descriptive components of the research (i.e., discussion of variables, estimation of the Ecological Footprint of the GFASI, and the development of the accounting framework) were approached.

4.2. Case study: overview, scope, and limitations

A review of the Global Farmed Atlantic Salmon Industry (GFASI) was undertaken as a case study. This section provides an overview of the case study approach as it was applied to the GFASI as a particular context for ecology-human health relationships. It also outlines the scope of the case study and discusses important limitations to the approach.

4.2.1. Overview

Case study investigations typically occur in clinical/medical contexts or in the population at large for case studies of programs, interventions, or relatively well-defined exposures. Medical case studies are considered the least valuable method of determining cause-effect relationships between exposures and outcomes; epidemiology textbooks typically describe the randomized controlled trial (RCT) as the most powerful method for this objective. However, as affirmed in the field of sociology, a discipline without an extensive foundation of case studies is a discipline without a systematic production of exemplars, and as such it is likely to be an ineffective discipline (Flyvberg, 2006). Because ecological epidemiology is an emerging field and one that has yet to establish strong theoretical foundations, effective methodologies, and indicators of human health which are sensitive to changes in ecological health in ways that overcome the obscuring mechanisms of buffering, exploring case studies of ecology-human health relationships is justified. The exploration of these kinds of case studies is also justified so long as epidemiology intends to be concerned with effectiveness in the service of the public's health.

The GFASI case study surveyed key features of the industry pointing to its total requirements for material resources and energy derived from the ecosphere, as well as the distribution and variety of drivers and inducers of pressures that create ecological change and thus lead to the types of human exposure contexts in which this study is interested. The case study also aimed at clarifying the most relevant questions to ask of any global industry that results in ecological impacts having implications for human health. The answers to these questions may differ markedly from industry to industry. The questions form part of the accounting framework which is developed in Chapter 5.

Most of the relevant information for the case study was obtained through a review of the literature, and from data abstracted from or derived from that literature. The case study was a descriptive, qualitative exercise in which some quantitative data were explored. Basic methods for both the qualitative and quantitative aspects are indicated in Table 7. below.

Table 7. Basic methods for quantitative and qualitative aspects of the study

Content Element	Method(s)
1. Quantitative	Literature and data search; abstraction and consolidation of relevant data
2. Qualitative	Literature review

4.2.2. Scope

The term, "Global Farmed Atlantic Salmon Industry (GFASI)," was coined to describe a particular multi-nation enterprise that contains dynamic economic relationships of supply and demand, and which is responsible for specific kinds of ecological impacts associated with the energetic and material demands, and the waste products, of the industry. An operational definition and justification of each word in the term provides a starting point for describing how the case study was scoped:

"**Global**:" Farmed salmon are produced by upwards of 20 countries, with Norway, Chile, the UK (Scotland) and Canada dominating production. As the industry has grown and those countries endowed with relatively unpopulated cold water marine coastlines have capitalized on their natural capital advantage, these top four producers now account for nearly 85% of the current farmed Atlantic salmon production (FishStat, 2004).Yearly production data are available for the top 16 producers (FishStat, 2004). The omission of total production numbers from producers not within the top 16 national producers for which data were more readily available was not considered likely to skew results since production volumes were negligible.

"**Farmed**:" Intensive salmon cultivation that employs land-based hatching and smolt development facilities and off-shore grow-out facilities is the most common method of salmon farming. Production and other figures associated with the GFASI come from production by this method. Other methods which may be called salmon "farming" include less controlled smolt husbandry combined with controlled adult grow-out operations (Anderson, 2002). Production and other data from these modes of production are not included in the case study. Certain elements of these other modes of production (e.g., absence of fixed-location net cage environments and different feeding routines) suggest an overlapping but different suite of ecological impacts.

"**Atlantic**:" Production data are for the Atlantic salmon (*salmo salmar*) species only. In some countries such as Canada, both Atlantic salmon and some Pacific species (e.g., Chinook) are farmed. However, globally, in 2004, Atlantic salmon accounted for approximately 90% of total farmed salmon production, and the farmed Pacific salmon species (chinook, coho, and sockeye) accounted for the remainder. Farmed Atlantic and Pacific species differ little in total feed and other requirements per kilogram of marketable fish; so, extrapolating any linearly related impacts from Atlantic salmon production volumes to all-species production volumes is straightforward. In terms of the broader ecological implications of farming salmon, however, it makes sense to analyze cultivated species separately; the economic decision to produce Atlantic and Pacific salmon species within the same operation obscures the fact that in wild populations there are distinctive ecological and distributional features of Atlantic salmon, as compared to the various Pacific salmon species.

"**Salmon**:" In some datasets, production data are consolidated for all salmonids, which includes trout species, but in most cases these data are provided on a species by species basis. Again, only Atlantic salmon data are considered. Some of the major farmed Atlantic salmon producers also farm other fish, including salmonids such as trout; where warranted and possible, the portion of the resources used by these firms for the production of Atlantic salmon alone is distinguished from the total resources consumed, whenever the total includes resources used for farming species other than Atlantic salmon.

"**Industry**:" A large portion of the production from global aquaculture comes from the small-scale, community- or family-level production of herbivorous fish such as carp and tilapia (FAO, 2004). Atlantic salmon, in contrast, are produced virtually entirely by large and consolidated companies with significant economies of scale. Data on community- or family-level production of farmed Atlantic salmon are thus not an issue of concern.

Presentations of descriptive data relevant to the GFASI, such as total production volume, are generally limited to the period from 1970 to 2004. Modern production of farmed Atlantic salmon goes back to the late 1960s, when Norway and Scotland sustained a few small operations (SeaWeb, 2006: www.seaweb.org). However, until the mid-1980s, farmed Atlantic salmon constituted only a very small proportion of total world aquaculture production. Figure 3. in Chapter 2 illustrates the global rise in production of farmed Atlantic salmon from 1970 through 2004.

Practically all of the current GFASI's output is produced in marine and brackish water environments. Some grow-out operations for farmed Atlantic salmon are still maintained in freshwater environments, but this constituted less than 1/2,000th of the total production in 2004 (FishStat, 2004). The local and regional environmental impacts from these operations differ in some respects from operations in marine and brackish water environments, but the energy inputs and material requirements for production are assumed to be very similar. Because the impacts of particular interest in this study are those stemming from the GFASI's contribution to humanity's ecological overshoot, plus regional-level ecological impacts realized in Peru, specific differences in environmental impact in the production areas are not of concern. However, application of the accounting framework outlined in Chapter 5 would include evaluation of the different ecological and human health impacts associated with production in these areas.

The source of feed for fish produced by the GFASI also affects the scope of this study. In particular, in the review of links proposed in the causal web described in Figure 13, the focus is on the GFASI's impact on the ecosystem that supports the anchovy fishery of Peru. Peru is the world's largest producer of fishmeal and fish oil, representing in 1999 more than 30% of the global landings of fish destined for reduction to fishmeal and fish oil (Delgado et al, 2003). Of this 30%, well over 90% are anchovies. Feed pellets used in the GFASI are in fact purchased from several suppliers, and the fishmeal and fish oil proportions of those feed pellets also come from a variety of suppliers and comprise a variable mix of fish species.

4.2.3. Limitations

The international scope of the farmed Atlantic salmon industry means that basic data on production volumes, operational features, and economic features are culled from a variety of national governments, international institutions and reporting entities. This means uneven data quality. Assumptions about data quality are consistent with those stated by agencies, such as the Food and Agriculture Organization (FAO) of the United Nations, that are responsible for monitoring and aggregating fish catch and aquaculture production data on a global scale.

Discussion of the Peruvian anchovy fishery is limited to basic historical, ecological, and political information. Selection of the variables listed in Table 10. was made on the basis of these variables being deemed likely to reveal basic GFASI features relevant to the determination of important associations and trends in the ecology-health relationships pertinent to the study population of interest. Inclusion of a variable for review and/or analysis was justified based on whether it actually did, or reasonably could be expected to indicate variation in another quantity included in the research proposition. The number of variables was limited for practical reasons. The propositional web in which the variables are causally connected is described in text form in section 4.4. and in Figure 13. as a schematic. The variables are listed in Table 10. Variables are grouped under themes that correspond to nodes in the schematic of the propositional causal web presented in Figure 13.

Market analyses, which might provide detail on the historical, present, and future demand for farmed Atlantic salmon (which drives the system) are limited in this study to quite superficial dynamics, again focusing only on those features which plausibly are connected to the operation of the anchovy fishery of Peru. Likewise, the extrapolation of historical production and other types of trend data to future years is limited to basic gross measures of industrial impact such as total volume of farmed Atlantic salmon production and total demand for Peruvian anchovy production.

Data on the species composition of fishmeal and fish oil are frequently lacking, even when production and market data are comparatively complete. This poses a limit to the accuracy with which calculations or predictions can be made of ecological impacts induced or exacerbated by the fishing activities of those entities supplying the fishmeal and fish oil processing plants.

4.3. Method for literature review

The initial searches for relevant general scholarly and non-scholarly literature on aquaculture and salmon farming were conducted mainly in the electronic databases

EMBASE, PAIS (Public Affairs Information Services), and the Centre for Agriculture and Biosciences International (CABI) Abstracts. Also, extensive use was made of the Google Scholar search engine, and, for non-academic "grey" literature, the standard Google search engine. Primary search terms included salmon, fish, aquaculture, Peru, anchovy/ies/eta and farm(ing).

Following leads from the reference lists of articles obtained in the initial searching became the dominant strategy early on in the investigation, reflecting the multi-disciplinary nature of the study. The dearth of literature on the kinds of ecology-health connections of interest in this research necessitated scanning reference lists in scholarly articles on one or two aspects of the research question, and then following links to other sources of information suggested in scholarly and non-scholarly papers. The progression of the literature review was from the very general to more specific aspects of the relationship between the Peruvian reduction fisheries and the regional ecology. Government sources were widely accessed for statistics and for reporting on industrial performance. In particular, IMARPE (Instituto del Mar del Perú) was accessed for purposes of comparison with FAO (i.e., FishStat) data on the Peruvian fisheries.

In addition to quantitative data on diet and nutrition in Peru, a limited amount of anthropological literature was reviewed. Searches for information on the nutritional geography and history of the Peruvian people, with a focus on fish, were conducted in several relevant anthropology journals through the University of Alberta's *Anthrosource* portal (www.anthrosource.net).

Some journals were searched for relevant content more intensively than others. The journals Ecological Economics (New York: Elsevier) and Environmental Health Perspectives (Research Triangle Park NC: National Institute of Environmental Health Sciences) and its predecessors were intensively searched for articles on the relationship between ecology and health at various scales.

4.4. Data sources and data quality issues

Data collected for review and analysis in this study were obtained primarily from public-domain, on-line electronic sources. Some data were abstracted from scholarly, governmental, industry, or non-governmental organization (NGO) publications for purpose of comparison. Data sources are shown in Table 8.

Table 8. Main data sources

Source	**URL and/or location of source**	**Data types**	**Info on data quality?**
World Resources Institute (Earthtrends), 2006. Key sources of data include FAO, 2006 and World Bank, 2006.	http://www.earthtrends.wri.org (Washington, DC)	Country-level population health data, economic and trade volume data, basic human nutrition data, and quantitative data on country-level environmental features	Yes for most variables

Source	**URL and/or location of source**	**Data types**	**Info on data quality?**
United Nations Food and Agriculture Organization (FAO). 2000-2006. Fisheries Global Information System (FIGIS). Rome: FAO. Sources of data compiled by the FAO for their dataset include national governments and government agencies.	FIGIS (FishStat Plus): http://www.fao.org/figis/servlet/static?xml=FIDI_STAT_org.xml&dom=org&xp_lang=en&xp_nav=3,1,2 Comparable data also available at: FishStat: http://www.fao.org/fi/statist/fisoft/fishplus.asp	Gross capture and aquaculture fish production volumes by fish species, country, area within country, and production environment (e.g., brackish water)	Yes; includes warnings about use of statistical tests where data quality is inconsistent; also provides detailed overview of data collection process
United Nations Food and Agriculture Organization (FAOSTAT), 2006	(http://apps.fao.org)	Indicators of food consumption, including nutritional variables, by type of food, year, and country	Yes; information on primary sources of data and data quality are provided

Source	URL and/or location of source	Data types	Info on data quality?
United Nations Environmental Program (UNEP) (GEO Data Portal), 2006	http://geodata.grid.unep.ch/	Data on multiple environmental, human health, and geographic variables; similar to WRI EarthTrends	Implicit from variable descriptions
World Bank, 2006	http://www.worldbank.org/wbsite/external/datastatistics/ (Washington, DC)	Country-level data on national debt, indices of national wealth, and health, nutrition, and population variables	Implicit from variable descriptions
United States Agency for International Development (USAID), 2006	http://www.usaid.gov/ (Washington, DC) (specifically, the Data On-line for Population, Health, and Nutrition—DOLPHN—at: http://dolphn.aimglobalhealth.org/	Country-level demographic, health, and nutrition data	Implicit from variable descriptions
Instituto del Mar del Perú (IMARPE)	http://www.imarpe.gob.pe/imarpe/ (Lima, Perú)	Annual and monthly catch volumes for various fish species and aquatic organisms from Peruvian waters; fishing capacity (vessels, hold capacity)	Implicit from variable descriptions
Pan American Health Organization (PAHO), 2001-2005	http://www.paho.org/english/dd/ais/coredata.htm (Washington, DC)	Prevalence of overweight in Peruvian and Canadian populations	Yes; provided with data

The sources noted in Table 8. are all data repositories, and as such consist of data on specific variables that are collected from different sources and by different means. The

WRI and UNEP rely heavily on FAO data; the USAID DOLPHN data portal relies on data from the World Bank, Centers for Disease Control and Prevention (CDC), WHO, and UNAIDS, among other sources.

Technical notes are provided by the data provider for most of the variables reviewed and analyzed in this study. The technical notes provide information on the meaning of the variable for which data have been consolidated, and in some cases mention is made of data quality, especially where the data have been collected from the reporting bodies of national governments and not directly by a single entity. Sieswerda et al (2001) extracted data from WRI datasets for their analyses, and noted large gaps in reporting by multiple countries on variables of interest. The authors noted that their sample of the world's countries was based on data availability. The availability of those data was not random and was reported as likely to have affected the relationships between EI and health outcomes that were identified in the study. Data quality and coverage concerns relevant to our case study will be noted in Chapter 7.

4.5. Research proposition and schematic

Public domain data and epidemiological reasoning were used to point to areas where knowledge gaps need to be addressed in order to meaningfully evaluate the evidence for a specific proposition about the relationship between a subset of ecological impacts associated with the global farmed Atlantic salmon industry and nutrition-related disorders associated with the quantity and quality of fish available for consumption by Peruvians. Important doubts and challenges relevant to investigating the accuracy of the proposition are discussed in Chapter 6. The proposition below is a more detailed version of the research question mentioned in Chapter 3, and is presented in the form of a positive statement. As a proposition, the extended statement below includes a number of claims which can be refuted or supported on the basis of existing evidence, or on the basis of evidence which, realistically, might be obtained. Some claims, such as those of the GFASI's impact on Peruvian ecological conditions via global processes (specifically, global warming), may be impossible to assess accurately but are, arguably, relevant to a comprehensive envisioning of the web of relationships. Also, information presented in sections 2.4.1 and 2.4.2. of Chapter 2 casts doubt on the assertion in the proposition that changes in the quantity (or quality) of fish available for consumption by Peruvians would be linked directly to certain nutrition-related disorders. We also recognize, with regard to population-health impacts related to changes in the Peruvian anchovy fishery, that ecological changes are not necessarily intermediary. Nevertheless, the proposition is employed in this study as a "straw man" through which a better understanding of the system it describes might be realized.

Research proposition: The global demand for farmed Atlantic salmon products has caused an increase in the global demand for farmed Atlantic salmon feed material. This demand has contributed to pressure for increased production of anchovies by the Peruvian anchovy fishery. Ecological changes stemming from this increased production and from downstream changes in the operation of Peru's fishmeal and fish oil processing industry, as well as from global-scale ecological changes to which the global farmed Atlantic salmon industry contributes primarily by fossil fuel combustion, have caused changes in one or both of two key features of the total supply of fish available for human consumption in Peru since 1970: quantity and quality. One or both of these changes is significantly related to one or more nutrition-related disorders in the Peruvian child or adult population.

Schematically, the research proposition can be represented as shown in Figure 13. below. The direction of the arrows indicates the proposed "cause"—for example, line 3 suggests that the global production of farmed Atlantic salmon causes a demand for anchovies, and line 6 suggests that this demand causes (in part) the Peruvian anchovy fishery to produce those anchovies.

Figure 13. Schematic of research proposition

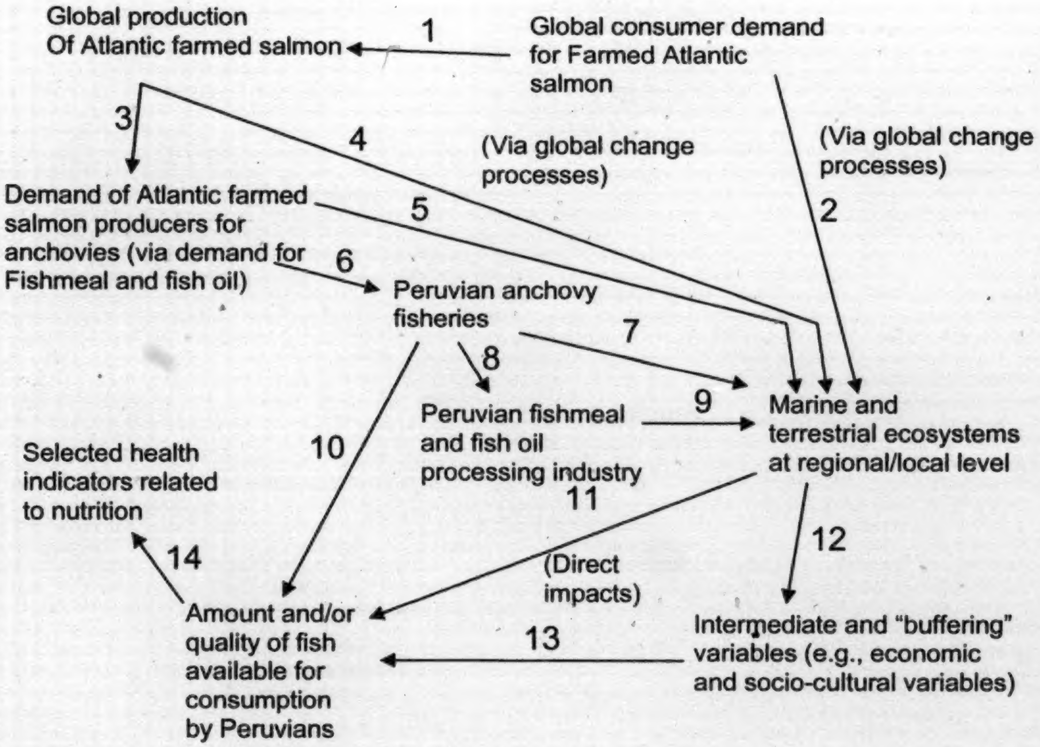

Global production
Of Atlantic farmed salmon
1
Global consumer demand for Farmed Atlantic salmon
3
4
(Via global change processes)
(Via global change processes)
2
Demand of Atlantic farmed salmon producers for anchovies (via demand for Fishmeal and fish oil)
5
6
Peruvian anchovy fisheries
7
8
Peruvian fishmeal and fish oil processing industry
9
Marine and terrestrial ecosystems at regional/local level
10
Selected health indicators related to nutrition
11
12
14
(Direct impacts)
Amount and/or quality of fish available for consumption by Peruvians
13
Intermediate and "buffering" variables (e.g., economic and socio-cultural variables)

Figure 13. shows that the research proposition states that pressures from the GFASI create changes to the anchovy fishery of Peru, which both directly and by way of impacts on Peruvian fishmeal and fish oil processing operations, in turn impacts marine and terrestrial ecosystems. These ecological impacts, which may occur at multiple scales, are postulated to act directly and through a variety of mediating forces to increase or decrease the quantity of fish and/or improve or degrade the quality of fish available for consumption by Peruvians. Also, the schematic shows that consumer demand for farmed Atlantic salmon products is an important driver of the system, and that global-scale ecological changes influenced by the GFASI (e.g., global warming) are predicted to ultimately affect the amount of fish or the quality of fish consumed by Peruvians. The size of the contribution of the GFASI to humanity's total contribution to global warming may be comparatively small, but the basic assumption is that the GFASI is burning carbon-based fuels while developing no new carbon sinks on the planet. This assumption and its implications are highly questionable; accurate carbon accounting is needed. Also, methods are needed for determining modes of action other than global warming by which global-scale drivers of ecosystem change ultimately impact relevant local/regional ecosystems.

Many other features of the Peruvian diet likely affect whether the amount or quality of fish consumed will lead to clinically significant nutrition-related disorders in the population, but certain outcomes are plausible and are represented by variables in the node to which the line labeled "14" leads. Chapter 5 contains a more detailed discussion of the relationships in the propositional causal web, and discusses salient areas of uncertainty.

4.6. Operational definitions and parsing of research proposition

Table 9. outlines the methods used or proposed for determining gaps in knowledge about the variables in the propositional causal web and the relationships between them. Only some of the methods were actually applied in this study. Following Table 9., operational definitions of key terms are provided.

Table 9. Terms in research hypothesis

Element in proposition	**Terms requiring operational definition (See section 3.5 below)**	**Method for qualifying or quantifying (measuring) element in proposition**
Changes in the anchovy fishery of Peru	• Changes Anchovy fishery Peru	• Analysis of anchovy catch data over time, along with fishing effort and relevant ecosystem and anchovy population dynamics
Driven by demand for farmed Atlantic salmon feed material	• Driven by demand (for) Farmed Atlantic salmon feed material	• Examination of relevant Peruvian fishmeal/fish oil consumption data over time; review of relevant industry statistics on sales from Peruvian fishmeal/fish oil production operations to GFASI producers
Have caused	• Caused	• Tests for strength of relationship, direction of relationship, and presence of likely confounders; evaluation of whole body of evidence for plausibility of causal relationship
Through the mechanism of ecological change	• Through the mechanism of Ecological change	• "Exposures" (see next row) must be the result of a causal process that starts with changes to the provisioning or buffering capacity of ecosystems; the pathway of impact may be direct or indirect

Element in proposition	**Terms requiring operational definition (See section 3.5 below)**	**Method for qualifying or quantifying (measuring) element in proposition**
A decrease in the quantity and/or quality of fish	• A decrease in the quantity/ a decrease in the quality of fish	• Quantity: review of total fish supply and per capita fish supply in Peru in years of interest Quality: analysis of species mix in total fish supply and per capita fish supply in Peru in years of interest; analysis of fish quality features such as freedom from chemical contamination, protein content, micronutrient content, palatability "Fish" as defined in FAO summary data: mass of all marine and freshwater animal organisms and products made from those organisms
Available for consumption by Peruvians	• Available for consumption by Peruvians	• Reference to FAO data on food supply ("apparent consumption") for Peru

Changes: Differences in quantity or quality from the value at a baseline or comparison year or group.

Anchovy fishery: Fishers, boats, gear, hours and days of fishing season, and regulations associated with the catching of the Peruvian anchovy (*Engraulis ringens*); includes all Peruvian anchovies caught for reduction (fishmeal and fish oil) and for direct human consumption

Peru: The Republic of Peru. Includes fishing areas within the administrative jurisdiction of the Peruvian government, as recognized by the United Nations.

Driven by demand (for): Strongly statistically associated and systemically associated with changes in consumption levels of the finished product (farmed Atlantic salmon).

Farmed Atlantic salmon feed material: Feed pellets consumed by farmed Atlantic salmon and containing fishmeal and fish oil.

Caused: Explained substantial amount of variation in outcome in the presence of a plausible story of mechanism of action.

Through the mechanism of: Via a specific mode of activity, such as a physical force.

Ecological change: Changes in the supply of the ecosystem goods or services outlined in Table 2. to which humans have contributed; loss of ecological integrity (EI); ecological collapse.

A decrease in the quantity: Quantitative decrease in mass or volume, according to the variable.

A decrease in the quality: Qualitative decrease (e.g., in palatability of fish) or quantitative decrease in specific constituents of total mass or volume which are associated with usual understandings of food "quality" in the relevant context (e.g., for "fish:" the protein content, levels of Omega-3 fatty acids, and levels of chemical contaminants).

Fish: by FAO definition: fish, crustaceans, mollusks, cephalopods, and other non-mammalian aquatic animals.

Available for consumption by: Constituting part of the food supply; actual "availability" will vary by sub-population, according to features such as income, price of product, and physical access to market.

Peruvians: Citizens and residents of the Republic of Peru.

4.7. Variables

Table 10. lists the variables considered for their representativeness of the concepts noted at each node of the proposed causal web. There is uncertainty about the suitability of each of these variables to describe each of the phenomenal concepts (nodes) in the web, but they are presented as a reasonable initial set of variables for use in further correlational analyses, testing for confounding and effect modification, and model building. Determining measurable quantities that reflect the content of the concepts of ecological integrity (EI) and human health is an ongoing process; many of the concepts in Figure 13. also require improved measurement.

The source of data for each variable is also indicated in Table 10. All data examined or presented in Tables and Figures in this study were downloaded from public domain websites, obtained from electronic documents, or obtained from hard-copy media such as print reports.

Table 10. Variables discussed and/or considered for causal relevance in this study

Node in research statement	**Variable**	**Type[1]**	**Years of data[2]**	**Source[3]**	**Justification[4]**
1. Global consumer demand for Farmed Atlantic salmon					
	Global sales of farmed Atlantic salmon (tonnes)	Cont	1970-2004	NYI	Indicator of consumer demand
	Global sales of farmed Atlantic salmon (value)	Cont	1970-2004	NYI	Indicator of consumer demand and willingness-to-pay
2. Global production of Atlantic farmed salmon					
	Total GFASI production	Cont	1970-2004	FishS	Necessary value for calculation of EF and of other discrete ecological impacts
	Total global farmed salmon production (Atlantic and Pacific species)	Cont	1970-2004	FishS	Necessary for distinguishing farmed Atlantic salmon impacts from impacts of entire farmed salmon industry
	Feed Conversion Factor (FCR):ratio of feed mass: salmon mass	Cont	1970-2004	NYI	Useful for projecting trends in impacts of industry related to technology change
	Conversion efficiency: ratio of anchovies: fishmeal and fish oil	Cont	1970-2004	NYI	Useful for projecting trends in impacts of industry related to technology change
	Conversion efficiency: ratio of anchovies: edible salmon mass	Cont	1970-2004	NYI	Useful for projecting trends in impacts of industry related to technology change
3. Demand of farmed Atlantic salmon producers for Peruvian anchovies (in fishmeal and fish oil)					
	Total volume of fishmeal and fish oil consumed by GFASI	Cont	1970-2004	NYI	Indicator of demand on global reduction fisheries by the GFASI
	Total value of fishmeal and fish oil consumed by GFASI	Cont	1970-2004	NYI	Indicator of economic impact of the demand on the global reduction fisheries by the GFASI; may be pertinent for projecting trends
	Total volume of Peruvian fishmeal and fish oil consumed by GFASI	Cont	1970-2004	NYI	Indicator of the size of the GFASI's demand on the Peruvian fishmeal and fish oil industry

Node in research statement	Variable	Type[1]	Years of data[2]	Source[3]	Justification[4]
	Proportion of anchovies in Peruvian fishmeal and fish oil	Cont	1970-2004	NYI	Partial measure of the contribution of the Peruvian anchovy fishery in particular to the impacts associated with the Peruvian fishmeal and fish oil processing industry
	Total consumption of Peruvian anchovies by GFASI	Cont	1970-2004	Calc	Indicator of the proportion of the Peruvian anchovy fishery for which the GFASI is directly responsible
4. Peruvian anchovy fishery					
	Total capacity devoted to anchovy fishery, Peruvian vessels	Cont	1970-2004	NYI	One factor useful for determining the likelihood of overfishing in the Peruvian anchovy fishery
	Total number of vessels devoted to Peruvian anchovy fishery	Cont	1970-2004	NYI	One factor useful for determining the likelihood of overfishing in the Peruvian anchovy fishery
	Average CO2 emissions per anchovy fishing vessels	Cont	1970-2004	NYI	Useful for calculation of the EF of the GFASI or of the Peruvian anchovy fishery in particular
	Total CO2 emitted by Peruvian anchovy fishing vessels	Cont	1970-2004	Calc	Useful for calculation of the EF of the GFASI or of the Peruvian anchovy fishery in particular
	Catch per unit of effort (CPUE), anchovy catch	Cont	1970-2004	Calc	Useful for consideration of technological trends in the industry, and as a rough measure of species abundance in fished areas
	Total Peruvian fish catch	Cont	1970-2004	IMARPE	Necessary for calculating total fish available for consumption by Peruvians
	Total Peruvian marine fish catch	Cont	1970-2004	IMARPE	Useful for determining qualitative features of the supply of fish available for consumption by Peruvians
	Total Peruvian catch destined for reduction	Cont	1970-2004	NYI	Necessary for determining ecological impacts of the Peruvian anchovy fishery
	Total Peruvian anchovy catch	Cont	1970-2004	FishS or IMARPE	Necessary for determining ecological impacts of the Peruvian anchovy fishery
	Total Peruvian by-catch associated with reduction fishery	Cont	1970-2004	NYI	Necessary for determining ecological impacts of the Peruvian reduction fisheries
	Total Peruvian by-catch associated with anchovy fishery	Cont	1970-2004	NYI	Necessary for determining ecological impacts of the Peruvian anchovy fishery
5. Peruvian fishmeal and fish oil processing industry					

Node in research statement	Variable	Type[1]	Years of data[2]	Source[3]	Justification[4]
	Capacity of fishmeal and fish oil processing plants in Peru	Cont	1970-2004	NYI	Useful information for determining limits on the ecological impacts from the processing plants
	Volume of fishmeal and fish oil processed in Peru	Cont	1970-2004	NYI	Useful for calculating values such as emissions or ecological impacts per unit of production
	Average toxic emissions to ocean per tonne of fishmeal or fish oil processed	Cont	1970-2004	NYI	Relevant for determining the relative contributions of the processing plants to regional/local scale ecological risks or changes
	Total toxic emissions to ocean from Peruvian fishmeal and fish oil processing industry	Cont	1970-2004	NYI	Relevant for determining contributions of the processing plants to regional/local scale ecological risks or changes
	Total Peruvian (non-fishmeal/fish oil) fish exports	Cont	1970-2004	NYI	Needed for determining total quantity of fish available for consumption by Peruvians
	Total value of Peruvian non-fishmeal/fish oil fish exports	Cont	1970-2004	NYI	Useful for determining economic features of Peruvian food fisheries; useful for predicting trends
	Total Peruvian non-fishmeal/fish oil fish imports	Cont	1970-2004	NYI	Needed for determining total quantity of fish available for consumption by Peruvians
	Total value of Peruvian non-fishmeal fish imports	Cont	1970-2004	NYI	Useful for determining economic features of Peruvian food fish supply
	Total Peruvian fishmeal and fish oil exports	Cont	1970-2004	NYI	Useful for industry trend analysis
	Total Peruvian fishmeal and fish oil exports value	Cont	1970-2004	NYI	Useful for industry trend analysis
6. Marine and terrestrial ecosystems					
	Mean Trophic Level (TL) of Peruvian marine fish catch	Cont	1970-2004	NYI	Gross indicator of ecological change
	TL of Peruvian reduction fish catch	Cont	1970-2004	NYI	Gross indicator of ecological change
	Mean marine water temperature in Peruvian anchoveta fishing zones	Cont	1970-2004	NYI	Indicator useful for analysis of periodic trends in regional/local scale ecosystems and in changes to parameters of the global marine environment
	Index of Biotic Integrity (IBI) in Peruvian anchovy fishing zones	Cont	1970-2004	NYI	More refined indicator of ecological change
	Index of Mean Functional Integrity (MFI) in Peruvian anchovy fishing zones	Cont	1970-2004	NYI	More refined indicator of ecological change
	Mean land temperature	Cont	1970-2004	NYI	Gross indicator of ecological change at regional/local scale and global scale

Node in research statement	Variable	Type[1]	Years of data[2]	Source[3]	Justification[4]
	El Niño years	O	1970-2004	NYI	Needed for distinguishing contribution of powerful natural phenomena from human pressures on ecosystems
7. Intermediate and "buffering" variables					
	Total fish products imports (Peru)	Cont	1970-2004	NYI	Needed for calculating total supply of fish available for consumption by Peruvians
	Exchange rates with countries from which fish are imported	Cont	1970-2004	NYI	Likely relevant as determinants of fish consumption in Peru
	Food aid from other countries or international organizations	Cont	1983-2004	NYI	Needed for framing fish supply within total food supply in Peru
	Food aid from other countries or international organizations that includes fish products	Cont	1970-2004	NYI	Needed for accurately calculating total food fish supply available for consumption by Peruvians
	Per kilogram price of fish in Peru relative to average of other substitutable sources of animal protein: chicken, pork, beef, mutton	Cont	1970-2004	NYI	Useful for determining influences on actual consumption of fish in Peru
	Average proportion of household budget spent on food products containing animal protein	Cont	1970-2004	NYI	Useful for determining influences on actual consumption of fish in Peru
	Average proportion of household budget spent on fish and fish products	Cont	1970-2004	NYI	Useful as a measure of the importance of fish in the Peruvian diet, and also of elasticity of demand if/when fish prices change
	Internal (domestic) food subsidies (Peru)	Cont	1970-2004	NYI	Needed for framing fish supply within total food supply in Peru
	Internal (domestic) fish products subsidies (Peru)	Cont	1970-2004	NYI	Useful for determining influences on actual consumption of fish in Peru
	Per capita internal monetary social support (Peru): transfer payments, emergency relief	Cont	1970-2004	NYI	Useful for consideration of "buffers" between changes in domestic fish production and capacity of the Peruvian populace to purchase fish
	Socio-cultural preferences for fish consumption	Dum (2)	< 1970 = 0; ≥ 1970 = 1	NYI	Useful for consideration of modifying effects of cultural changes on the domestic fish supply on
	Socio-cultural preference for anchovies as human food	Dum (2)	< 1970 = 0; ≥ 1970 = 1	NYI	Useful for examining changes in socio-cultural preferences during period of GFASI that influence total fish supply available for consumption

Node in research statement	**Variable**	**Type[1]**	**Years of data[2]**	**Source[3]**	**Justification[4]**
	Gross Domestic Product in Purchasing Power Parity (PPP), per capita, Peru	Cont	1970-2004	WRI	Useful for examining income as a potential "buffer" between domestic fish production and total fish actually consumed
	Balance of trade, Peru	Cont	1970-2004	NYI	Useful for establishing trade in fish in context of larger trade dynamics in Peru
	Amount and proportion of Peruvian GDP for which all fisheries, and the anchovy fishery in particular, are responsible	Cont	1970-2004	NYI	Useful for determining the monetary (and possibly the related health) benefits of industries which in part are responsible for, and potentially benefiting from, ecological change
	Implementation of economic policies implemented under Alberto Fujimori (in power 1990-2000)	Dum (3)	1970-89; 1990-2000; 2001-2004	NYI	May have value in revealing modifying effects of major political/economic policy changes in Peru
	GINI (income equality)	Cont	1970-2004	WRI	Useful for determining equity-related features of income as a buffer between reduced domestic fish supply and actual consumption
	Population (Peru)	Cont	1970-2004	WRI	Necessary for per capita calculations
	Urban population as a proportion of total population (Peru)	Cont	1970-2004	WRI	Useful for better understanding the relationship between changes in residence and lifestyle and changes in diet (such as fish consumption)
	Age structure of population (Peru)	Cont	1970-2004	NYI	May be valuable in providing further interpretive insight into any per capita values which are calculated (such as per capita fish consumption or per capita income)
	Daily per capita caloric intake from animal products	Cont	1970-2004	WRI	Useful for establishing dietary framework in which changes in fish consumption take place; ideally, data would be available for various social and demographic strata
8. Amount of fish and fish protein consumed by Peruvians					
	Fish protein as percentage of total Peruvian protein supply	Cont	1970-2004	WRI	Useful for establishing the importance of fish in the total protein intake of the population, a factor which may be relevant when considering nutrition-related disorders; ideally, data would be available for various social and demographic strata

Node in research statement	Variable	Type[1]	Years of data[2]	Source[3]	Justification[4]
	Per capita Peruvian food supply from fish and fisheries products	Cont	1970-2004	WRI	Basic proxy for Peruvian fish consumption
	Calories per day from animal products (Peru)	Cont	1970-2004	WRI	Useful for establishing part of the dietary framework in which fish consumption takes place
	Calories per capita per day (Peru)	Cont	1970-2004	WRI	Useful for establishing part of the dietary framework in which fish consumption takes place
9. Selected health indicators related to nutrition					
	Under 5 mortality rate, Peru	Cont	1970-2004	WRI	Traditional composite indicator of maternal and child health
	Prevalence of underweight[5] in children 0-5 yrs., Peru	Cont	1970-2004	WRI	Basic marker for dietary (nutrition) deficits
	Prevalence of stunting[6] in children 0-5 yrs., Peru	Cont	1970-2004	NYI	Basic marker for dietary (nutrition) deficits
	Prevalence of wasting[7] in children 0-5 yrs., Peru	Cont	1970-2004	NYI	Basic marker for dietary (nutrition) deficits
	Mean proportion of household food budget used to purchase fish at 1970 level of consumption, Peru	Cont	1970-2004	NYI	May provide a way of measuring temporal trends in the importance of fish to consumers
	Prevalence of overweight/obesity in adult population	Cont	1970-2004	NYI	Basic indicator for over-nutrition
	Prevalence of CVD in adult population	Cont	1970-2004	NYI	May be a useful indicator of over-nutrition

1 Types of variables are noted as follows: Cont = Continuous range of values; Dum (x) = Dummy variables (number of categories); O = Non-continuous range of values (e.g., categorical variable on ordinal scale)

2 Years of data are based on years for which reliable GFASI production data are available; deviations or variables with missing data are noted in the analyses. In some cases, 1970 is taken as the reference year for the calculation of the value of a variable (e.g. Mean proportion of household food budget used to purchase fish at 1970 level of consumption, Peru). In other cases, historical reference values for variables are noted and interpreted.

3 Primary data sources are indicated as follows: WRI = World Resources Institute; IMARPE = Instituto del mar del Perú; FAO = Food and Agriculture Organization of the United Nations; FishS = FishStat, a global fishing database maintained by the FAO; Calc = variable calculated from other variables; NYI = Not Yet Identified.

4 A variable was considered justified for review and/or inclusion in the analyses if it indicated (or might indicate) change in any of the functional components (e.g., changes to Peruvian reduction fisheries) of the research proposition, as represented by the nodes in Figure 13.

5 WHO definition (underweight): For children 0-4 years combined, > 2 standard deviations below median weight for age as defined by the NCHS/WHO international standard.

6 WHO definition (stunting): For children 0-4 years combined, > 2 standard deviations below median height for age as defined by the NCHS/WHO international standard.

7 WHO definition (wasting): For children 0-4 years combined, > 2 standard deviations below median weight for height as defined by the NCHS/WHO international standard.

4.8. Univariate analyses

Univariate analyses consisted of describing certain elements of the GFASI, discussing characteristics of, and trends in many of the variables in Table 10., and estimating and discussing some of the implications of the EF of the GFASI. Stata 9 statistical software (StataCorp, 2005) and the FishStat interactive database maintained by the FAO (FishStat, 2004) were used for producing the non-excerpted graphs and tables of values included in this paper. Figures and tables abstracted from other works are credited in the text.

4.8.1. Exploration of descriptive elements of the GFASI in the case study

The global farmed Atlantic salmon industry (GFASI), as a generator of human health impacts associated with ecological change induced by the industry, was explored in Chapter 2. through a narrative of the web of effects implicated in an act of consumption of farmed Atlantic salmon. The non-fiction aspects of the narrative (i.e., the statements about the life-cycle impacts of the serving of farmed Atlantic salmon) were determined from a mix of grey and academic literature cited elsewhere in this study. The narrative was followed by a brief overview of the industry's history and ecological and economic characteristics. In Chapter 5, various historical and ecological features of the Peruvian anchovy fishery (which in our research proposition is a central driver of ecological change at the regional/local level in Peru) are described. No special methods beyond a non-systematic literature review were employed for these descriptive elements.

4.8.2. Discussion of variables

Variables are discussed in terms of their identities and modes of action within the causal structure proposed in Figure 13. In many cases in this discussion, questions are raised about the appropriateness of a variable, and qualifications on its mode of action are noted.

4.8.3. Estimation of the EF of the GFASI

The ecological footprint of the GFASI was estimated for one year of production (2004) by extending Tyedmers' (2000) values for the EF for the British Columbia (BC) farmed Atlantic salmon industry. In Tyedmers' analysis, information on inputs to production included data up to 1998. Energy and material demands of the industry, expressed in EF global hectare terms, were determined. This was accomplished through an analysis of the demands of the subsystems supporting these industries, including smolt (young salmon) production, marine grow-out operations, adult salmon transport, salmon feed production (from reduction fish, agricultural crops, and terrestrial livestock meals), and grow-out infrastructure such as net pens (Tyedmers, 2000). (For reference, Table 61. on page 137 of Tyedmers (2000) provides a summary of the energy demands of all the subsystems, and includes the total marine and terrestrial global hectares of ecosystem support area required. Tyedmers employed a variation of embodied energy analysis, for example by including the energy demands of harvesting, processing, and transporting agricultural products in the total energy costs of those products.) We assumed rough equivalency of energy and material demands for farmed Atlantic salmon production in the major producing countries in 2004 (Table 15. in this thesis discusses the justification of this assumption), and multiplied Tyedmers' value for the EF for the production of one round tonne (wet weight of whole carcass) of farmed Atlantic salmon by the total production of these countries in 2004.

The aggregate EF for the GFASI provides a gross measure of the industry's sustainability and indicates the relevance of looking into regional/local level ecological impacts, at various time scales, should the industry be found to be ecologically unsustainable at the macro level. The consideration of specific regional/local scale ecological impacts associated with the production of one key input to the industry (i.e., Peruvian anchovies) provides a model for investigating ecological impacts associated with other inputs to the industry. This broadens our understanding of how farmed Atlantic salmon consumers in wealthy nations are related to populations affected by ecological changes associated with the foreign production of key inputs to the industry such as fishmeal and fish oil derived from Peruvian anchovies.

4.9. Developing the accounting framework

The accounting framework was developed in stages and is based on addressing the four key questions noted in section 2.5.4. This development was guided by a non-systematic review of the literature on composite indicators of social well-being, and also of existing analytical methods for determining ecosystem health.

Chapter 5. Results

5.1. Outline of this chapter

This chapter begins with a review of the Peruvian anchovy fishery, which brings the general discussion begun in Chapter 2 into the more specific realm of the GFASI's implications, via regional/local scale drivers of regional/local scale ecological changes in the Humboldt Current Upwelling Ecosystem (HCUE), for population health in Peru. Then, variables first introduced in Table 10. are discussed with the intention of showing their potential relevance, ultimately, to the population health outcomes in the propositional causal web shown in Figure 13. Next, we calculate the EF of the GFASI for one year (2004) of production, and discuss the meaning of the GFASI's ecological footprint mainly in terms of global-scale drivers (such as global warming) of regional/local scale ecological changes that may bear on the population health impacts noted in Figure 13. Finally, this chapter discusses the further practical development of the accounting framework, continuing on from the introductory sections on this analytical tool which were provided in Chapter 2.

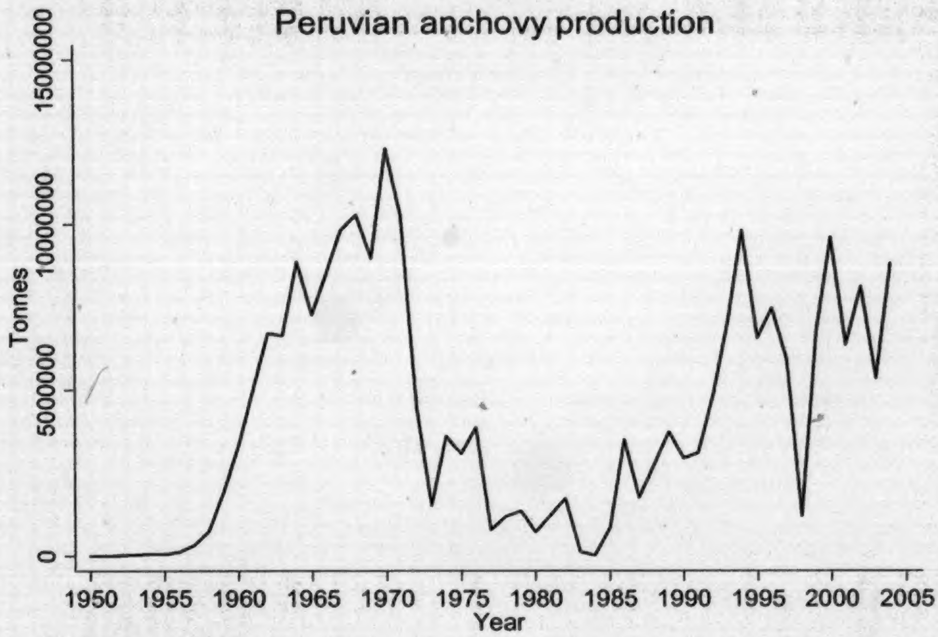
5.2. The Peruvian anchovy fishery

Purchases by farmed Atlantic salmon producers of fishmeal and fish oil from Peru are overwhelmingly purchases of processed anchovies. The reduction fisheries of Peru are dominated by *engraulis ringens*, the Peruvian anchovy. Approximately 90% of Peruvian fishmeal and fish oil consists of processed anchovies. Except for ENSO years when catch volume can fall sharply, the Peruvian anchovy fishery remains the largest single-species fishery in the world (Chavez et al, 2003).

According to Ibarra et al (2000), exploitation of abundant natural resources has long underpinned economic development throughout Latin America. The Peruvian anchovy (anchoveta) fishery, hereafter "anchovy fishery," was launched as an industrial enterprise in the late 1930s, and the subsequent history of the industry is full of dramatic domestic political intrigue as well as the influences of the rapidly globalizing economy. From the mid-1950s through the beginning of the 1960s, pro-fishing economic policies in Peru, including the establishment of a 200-mile territorial limit to exclude foreign exploitation of stocks, established the anchovy fishery as a major source of foreign exchange. Almost all the fishmeal and fish oil from the reduction process was sold to Europe, and the primary end use was poultry feed.

With substantial booms and busts in the decades since investment in the anchovy fishery as an industrial enterprise began, by 1970 all-species fishing in Peru accounted for approximately 30% of the country's export earnings, and the anchovy fishery accounted for about 98% of the catch of Peruvian fish (IMARPE, 2005).

Figure 14. Peruvian anchovy production, 1950-2004



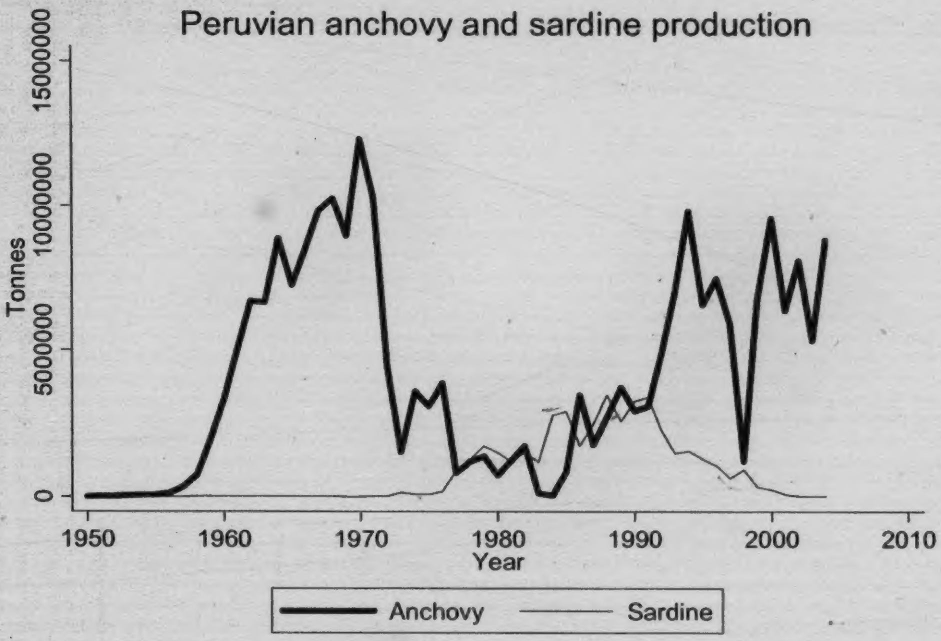
(Source of data: FishStat, 2004)

Figure 14. shows the very large variation in the size of the anchovy catch from year to year. El Niño/ENSO events in 1972, 1982-83, and 1997-98 are largely deemed responsible for especially low catch volumes in those years and the years immediately following. After the ENSO event of 1972, the Peruvian government effectively nationalized the fishing industry and formed the para-governmental corporation named Pesca Peru. In 1976, a new federal government introduced changes to Pesca Peru that reduced some of the public benefits (such as a wealth-distribution scheme to support less productive fishers) that had been part of the corporation's initial constitution. In 1980, yet another new federal government attempted to re-establish Pesca Peru's sovereignty over fishing operations in Peru, but by the early 1990's Pesca Peru's share of anchovy production in particular had been steadily falling as private enterprise and foreign investment were expanded under Peruvian President Alberto Fujimoro's administration.

In 1999, Pesca Peru was slated for liquidation (Ibarra et al, 2000). The most important basic lesson for the current study about the history of Pesca Peru is that governmental agencies and policies, affected by variable political and economic pressures, can profoundly affect activities such as fishing which in turn have ecological implications.

Although historically anchovies have comprised the large majority share of the Peruvian fish catch destined for reduction to fishmeal and fish oil, in many years other species such as sardine have contributed substantially. The ecological relationship between anchovy and sardine populations in the HCUE continues to be a topic of scientific interest, and one that is relevant to future fisheries management (Guillaume, 2005; Bertrand et al, 2004; Chavez et al, 2003). Figure 15. presents Peruvian catch data for anchovy and sardine.

Figure 15. Peruvian anchovy and sardine production, 1950-2004



(Source of data: IMARPE, 2005* Note: The sardine catch data from 2000-2004 are of uncertain quality; they were obtained from a non-citable draft document and were attributed in that document to the Peruvian Ministry of Production (2004))

Superficial examination of the trends in Figure 15. gives the impression that the catch volumes of the two species may be roughly inversely related from the mid-1970s through the mid-1990s, but the precise relationship is not clear. It is important to note that the relative catches of anchovy and sardine are not a highly accurate indication of the available stocks of either species in a given year, and thus these data do not represent the underlying ecological relationship between anchovy and sardine, let alone between the anchovy, sardine, and all of the other organisms in the HCUE. Variation in fishing effort, variation in national fishing regulations, and variation in international market forces, among other things, provides the shape of the graphed lines for each species (see, for example, Ibarra et al, 2000). The ENSO events of 1972, 1982-83, and 1997-98, while related to the dramatic drop in anchovies caught in those and immediately subsequent years, affected the sardine catch uncertainly. It is commonly understood that sardines thrive in the warmer waters created by the El Niño events, while anchovies flourish in the colder waters prevailing in non-El Niño years (Pauly and Tsukayama, 1987), although new data suggest that the situation is much more complex (Bertrand et al, 2004). Again, however, from these data alone the effect of the El Niño events cannot be conclusively distinguished from the other human and natural factors influencing the annual catch volumes of these two fish species. Pontecorvo (2001) also points out that the El Niño phenomenon is not defined such that the inception of its impact on a stock of fish (i.e., a yield or production function) can be clearly identified.

The Peruvian anchovy fishery also provides an instance of how the buffering of negative and potentially corrective ecological feedback, for example by the deferment of consequences into the future, can be present even in the absence of international trade. One of the adaptation techniques of the anchovy in the face of predation is to form tight shoals. As the overall population decreases, these shoals remain relatively constant in size but their number declines and they are dispersed over a smaller area. This intensifies the vulnerability of the fish to the purse seining approach predominant in the anchovy fishery in Peru. Thus, while the warm waters of the El Niño may be reducing the anchovy habitat as a whole, the concentration of the fish in some areas may actually increase; as such, catch rates may not immediately reflect the underlying decrease in stock size, and thus those catch rates will not serve as an "early warning" indicator of overfishing. This can contribute, as it likely did in the midst of the 1972 El Niño event and immediately following, to greater ecological change *vis-a-vis* the anchovy population than would be expected based on the influence of the El Niño event alone (Ibarra et al, 2000).

Part of the period of the GFASI's dramatic upturn in production, from the early 1980s through the mid-1990s, occurred during the time when the anchovy fishery of Peru was still largely controlled by Pesca Peru, the public fishing corporation. The GFASI then continued to grow rapidly throughout the 1990s, after the anchovy fishery in Peru had been returned substantially to private interests. Because there have been, and continue to be, political and economic forces shaping the Peruvian anchovy fishery before the onset of, and now during, the period of the GFASI's global-scale production, the specific pressure of the demand for fishmeal and fish oil by the GFASI (and thus for anchovies from Peruvian waters) is difficult to detect or quantify without accurate sales data from all buyers in all sectors. The prices of fishmeal and fish oil are determined in the world market, as are the prices for other animal feed components such as corn and soy meal (Pontecorvo, 2001). In contrast to major grain or oilseed products like corn and soy, however, fishmeal and fish oil futures are not purchased, and transactions tend to be private (Durand, 1998). The prices of fishmeal and fish oil relative to other imperfect substitutes, the rate at which the GFASI grows, and the rate at which plant-derived substitutes for fishmeal and fish oil are actually incorporated both into farmed Atlantic salmon feed and into livestock feed, are important variables in the estimation of the future impact of the GFASI on regional/local ecological conditions. The magnitude of these ecological changes will vary by farmed Atlantic salmon producing country because of different economic policies, mixes of livestock versus farmed Atlantic salmon and other aquaculture production, and different types of production technology (Tveterås et al, 2003).

The ability of the Peruvian government to control anchovy fishing effort and thus catch volume is a critical variable in the propositional causal web that implicates anchovy fishing with regional/local ecological change and that assumes a growing demand for fishmeal from a growing GFASI. As Ibarra et al (2000) point out, forces such as needs to increase short-term employment, domestic food production, and export earnings can be at odds with conservation or sustainable yield management of the anchovy and other fisheries, and high prices can create the paradoxical effect of increasing fishing effort when fish are scarce (Asche and Tveterås, 2000).

Another key question is whether the anchovy fishery of Peru at its current production level is truly sustainable. Clearly, in years when El Niño effects are felt, the catch must drop considerably if the remaining breeding stock in the diminished habitat is to survive; however, lack of knowledge about the relationship between anchovy populations and El Niño events suggests that in any season the catch limit is a rough estimate only. Better data are needed on the relationship between the El Niño and the entire SO phenomena, the ecology of the HCUE, and the way that human fishing efforts are situated in and affect these systems.

Peru has moved from an open-access anchovy fishery, through largely failed experiments with fishing season duration limits and some types of catch quotas, to its current management system of using approaches such as Individual Transferable Quotas (ITQs), strict licensing policies for fishmeal/fish oil plants and fishing vessels, and fishing fees (Ibarra et al, 2000). There is no indication that demand pressure specifically by the GFASI had any role in forcing the adoption of this system.

Future trends in fishmeal and fish oil demand are often discussed in terms of shifting demand between sectors rather than in terms of overall increased demand. According to Delgado et al (2003), the high price elasticity for fishmeal in the livestock sector appears to have allowed a distributional change in the end-uses of fishmeal. The situation is similar in kind for fish oil, and the shift in use from other sectors to that of aquaculture has been even greater. Both Atlantic and Pacific farmed salmon species are fed a diet of feed pellets containing a far larger proportion of fish oil than the feeds for other farmed fish species (Tacon, 2001). However, should the rapid growth seen in the GFASI in the past 20 years continue, demand for fishmeal and fish oil will likely increase, especially since, for nutritional reasons, there appears to be a limit on the extent to which plant-derived meals and oils can be substituted for fishmeal and fish oil in farmed Atlantic salmon production.

Because, for cultural reasons, the volume of anchovies consumed directly by humans in Peru is small, and not only because most of the anchovy catch processed into fishmeal and fish oil is exported, the anchovy fishery itself currently contributes little to the human food fish supply in Peru. However, since anchovies are prey for some of the fish species which are, in fact, consumed directly (such as squid and hake), the relevance of changes in the Peruvian anchovy fishery to the quantity and quality of domestically produced fish available for consumption by Peruvians may be more evident at the ecosystem level. Regular modeling of the flows of biomass between trophic levels in marine ecosystems is one way to determine the relative importance of predator species (including human beings) to the population sizes of other species of interest (Jarre-Teichmann, 1998), but this thesis can only suggest the importance of the issue to a fuller investigation of the relationships described in the causal web in Figure 13.

Delgado et al (2003) maintain that it is unlikely that global fishmeal price increases (as a result of an increased gap between supply and demand) would immediately result in the conversion of low-value food fish (such as some of the species fished from Peruvian waters and consumed directly by humans in Peru) to fishmeal and fish oil, potentially reducing the quantity and quality of fish available to Peruvians for consumption. These authors also contend that because of the substitution of demand by aquaculture for demand by the livestock industry, the growth of aquaculture, and by association, that of the GFASI, has not yet been responsible for placing increased pressure on the world's reduction fisheries—such as the Peruvian anchovy fishery. If correct, this does still not suggest that the growth of the GFASI thus far has not contributed to negative ecological impacts from reduction fisheries which are already in an unsustainable mode. As noted, uncertainties about the thresholds and dynamics of the HCUE do not allow the conclusion that the Peruvian anchovy fishery has been sustainable or will be sustainable at current production rates.

An additional issue not explored in depth in this study is that of the ecological impacts of the waste and effluent produced by fishmeal and fish oil processing plants (e.g., Ahumada et al, 2002; Arcos et al, 1993). The GFASI is unlikely to play a direct role in this process by which regional/local scale ecosystems may be impacted, but the global demand for fishmeal and fish oil requires a certain processing capacity which has its own industrial metabolism, and which implies a system of interconnected ecological impacts (Ayers, 1998).

In summary, it does not appear that the operation of the Peruvian anchovy fishery, and especially its expansion in the past several decades, has been directly influenced by the rapid 20-year growth in the GFASI. Although mismanagement has been noted (Ibarra et al, 2000) and anchovy stock crashes have been experienced, anchovy fishers have had a large but variable market for fishmeal and fish oil for decades. Increased consumption of fishmeal and fish oil by the GFASI seems to parallel a decrease in consumption of these same products by poultry and pig producers, who have begun to substitute more plant-based ingredients into their feeds. Delgado et al (2003) suggest that fishmeal has been reallocated to the aquaculture sector because as overall demand has grown, supply has remained roughly the same. As a result, terrestrial livestock producers (mostly poultry and pig producers) have switched to vegetable-based meals.

It seems that the influence of the GFASI on the Peruvian anchovy fishery is largely obscured in the aggregate, however; not all of the major farmed Atlantic salmon-producing countries purchase fishmeal and fish oil made from Peruvian anchovies. It would be useful to examine the business relationships between those countries like Canada and the United States, which regularly purchase Peruvian anchovies in the form of fishmeal and fish oil, and Peruvian fishing and fishmeal/fish oil processing companies. Greater detail on these "micro-" level relationships could shed light on the mechanisms by which anchovy fishing pressure is applied in Peru. Also, some major GFASI firms are increasingly vertically integrated, owning not only farmed Atlantic salmon grow-out operations, but also components of the feed supply chain (Harris, 2006). An extension of this "vertical integration" to include segments of industrial reduction fisheries, like the anchovy fishery of Peru, is not difficult to imagine in a world where marginally improved information about, and control over, inputs can be profitable.

5.3. Discussion of variables

Although there may be other mechanisms, we have focused on the most obvious major driver of regional/local scale, distal, ecological change: the Peruvian anchovy fishery. As Figure 13. shows, regional/local scale ecological changes relevant to the quantity and/or quality of fish consumed by Peruvians, are proposed to be driven by changes in (1) the Peruvian anchovy fishery itself; and (2) the Peruvian fishmeal processing industry that turns anchovies into fishmeal and fish oil. Ecological impacts of the former have to do with the anchovy stock and the dynamics of the marine ecosystem in which the anchovies live. The ecological impacts of the latter are related to toxic effluents from the processing plants that change or degrade the marine ecology. Global scale impacts of the anchovy fishery and the processing plants that result from the combustion of fossil fuels for locomotion and electricity generation are subsumed in the discussion of impacts associated with the aggregated EF of the GFASI.

In Table 10., nine different nodes in the propositional causal web are noted, and there are multiple variables associated with each of these nodes. The first three nodes (global consumer demand for farmed Atlantic salmon, global production of farmed Atlantic salmon, and the demand of farmed Atlantic salmon producers for Peruvian anchovies in fishmeal and fish oil) include variables that reasonably might be used to measure the concepts described by the nodes. Several of these variables were mentioned in the context of the general discussion of sections 2.3.1. and 2.3.2., and only a few will be discussed further in this section. A selection of variables corresponding to the other nodes of the propositional causal web are also discussed. Some of the variables included in Table 10. would only be used to calculate or to cross-check the accuracy of values associated with other variables in the same table; these are not discussed.

The variables below are considered in terms of how they are predicted to affect the proposed causal chains that run from the Peruvian anchovy fishery, through and past regional/local scale ecological changes relevant to that fishery and related fisheries, and ultimately to nutrition-related population health impacts in Peru. They are considered in the order in which they appear in Table 10.; again, not all variables in Table10. are discussed.

1. Total volume of fishmeal and fish oil consumed by GFASI

This pair of variables provides a denominator so that we can then determine what proportion of Peru's annual fish meal and fish oil production is used for the production of farmed Atlantic salmon. Knowing the anchovy content in both Peruvian fishmeal and fish oil, we can then roughly determine the amount and proportion of total Peruvian anchovy production that is appropriated for the global production of farmed Atlantic salmon. This does not directly tell us anything about the ecological impacts of the Peruvian anchovy fishery, but it does permit the determination, by relative demand, of the extent of the GFASI's participation in causing those impacts.

2. Proportion of annual consumption of fishmeal and fish oil by GFASI that is from Peru
This pair of variables, along with the denominators mentioned immediately above, enables determination of the contribution of Peruvian fishmeal and fish oil production to the total amount consumed by the GFASI.

3. Species composition of fishmeal and fish oil produced from Peruvian fish
Our interest in the ecological implications of the Peruvian anchovy fishery requires that the proportion of anchovies is known for the fishmeal and fish oil produced in Peru. This is for two reasons. First, changes in the mix of species used to produce fishmeal and fish oil suggest changes in the relative abundance of these species in the marine environment, though a change in the mix may also reflect other influences (for example, differential incentives for catching different species, natural seasonal variation, changes in consumed demand requiring different protein and mineral content in the fishmeal or fish oil). Second, changes in the mix of species, and in particular the proportion of Peruvian anchovies in the mix, enables the determination of the relative contribution of the Peruvian anchovy fishery to any regional/local ecological implications of Peruvian fishmeal and fish oil processing operations

4. Number and capacity of Peruvian fishing vessels devoted to capture of anchovies
These two variables, which are noted independently in Table 10., are important for the determination of maximum anchovy catch in the short term. In combination with enforced fishing regulations, and provided that there is no movement of domestic boats from other fisheries to the anchovy fishery, the number of vessels and their capacity poses a limit to the volume of anchovies that can be caught in specified period of time. These features of the fishery imply that any model that is to reflect the real world must not assume *a priori* that capacity is currently present to catch all the anchovies that could potentially be caught in a given year. In fact, these two variables are typical of a large

number of variables that have to do with available fishing technology and other mechanical determinants of the total anchovy catch in a given year.

5. Total marine fish catch (Peru)

Variation in the total marine fish catch, in years with comparable levels of fishing effort, may reflect underlying ecological changes that are either independent of, or related to changes in the population dynamics of the Peruvian anchovy and the fishing effort applied to this species. In addition, since Peruvians do not consume anchovies directly in large quantities, the size of the total marine fish catch, minus the total catch of anchovies and the other reduction fish, provides a baseline for fish quantity from the marine ecosystem that is available for consumption by Peruvians prior to the operation of export and import buffers.

6. Total fish catch, marine and inland (Peru)

Compared with the total marine fish catch, the total fish catch from both marine and inland fisheries shows the relative importance of non-marine (freshwater) fisheries to the total quantity of fish available to Peruvians for consumption, again prior to export and import adjustments. If the inland fishery is large and the terrestrial ecology is healthy, negative impacts from the Peruvian anchovy fishery on the marine ecology will be less important in the short term to the total fish supply available to Peruvians. This is in principle only; inland fisheries in countries with large coastlines and well established marine fisheries usually contribute only a tiny fraction of the total fish supply.

7. Total Peruvian anchovy catch

This variable is important for several reasons:

i) Catch data reflect something of the underlying population and/or distribution of the fish stock;

i) The total volume of anchovies extracted from the ecosystem has ecosystem-wide implications;

ii) Anchovies are consumed by other marine organisms which may be used in Peru for human consumption;

iii) A very small proportion of the anchovies caught annually are consumed by Peruvians. National policy and advocacy efforts aim at increasing this proportion; and

iv) An increasing share of world fishmeal and fish oil production is consumed by the GFASI, and Peruvian anchovies continue to constitute a near-majority share of the marine organisms used for this purpose.

As indicated elsewhere, the total annual catch of Peruvian anchovy is characterized by extreme variation, in large part as a consequence of temporary habitat changes brought on by ENSO events.

8. Total annual Peruvian catch of all species destined for reduction

In relation to the total catch of anchovies and the other variables, including Peruvian fishmeal and fish oil processing capacity, the total annual catch of fish destined for reduction permits the determination of certain quantities, such as: the proportion of the annual fishmeal and fish oil production of Peru consisting of anchovies, and of non-anchovy species; the total extraction from the marine ecosystem of organisms at roughly the same trophic level (i.e., the level consisting of organisms that feed on primary or secondary producers like phytoplankton and zooplankton, since almost all fish destined for reduction in Peru fall into this category); and the ratio of anticipated throughput to processing capacity. These quantities, which are related at least indirectly to the Peruvian anchovy fishery, may bear on ecological impacts in the present or the future, and, via those impacts, on quantity or quality of fish available for consumption by Peruvians. This could occur either through changes in the physical features of the domestic catch available for consumption or by changes in certain domestic and international monetary flows (e.g., export earnings from the sale of fishmeal and fish oil on the global market, including sale to the GFASI) that influence the economic availability of different types of fish for consumption by Peruvians.

9. Total annual by-catch (discarded and processed) associated with Peruvian reduction fisheries

By-catch, defined as the inadvertent catch of organisms that were not specifically targeted by a fishing operation that are either discarded or landed for commercial sale (Delgado et al, 2003) is estimated by the FAO (2000) to represent nearly 25%, or approximately 20 million tonnes, of the total annual global fish catch. As Delgado et al (2003) note, non-target species tend to be overlooked by conventional assessment and management; thus, the impacts of caught and killed organisms on the ecosystems from which they are extracted may be even less well defined than for target species. Some of these changes may affect the quantity or the quality of fish such as anchovies which are destined for reduction into fishmeal and fish oil, and for limited human consumption, or of the quantity and quality of fish that are fished from Peruvian waters and intended for human consumption. Although it would be difficult to predict just from volume figures and not also from species-specific information, large volumes of by-catch or regular by-catch from sensitive areas could have ecological implications.

10. Capacity of fish processing (fishmeal and fish oil producing) plants in Peru

For many years, the total capacity of Peru's fishmeal and fish oil processing plant has far exceeded the actual throughput of reduction fish. This means that this variable, from a physical if not economic perspective, is unlikely to place a limit on the anchovy catch in future years. It is not clear whether the presence of excess capacity tends to exert pressure on the anchovy fishery to overproduce, so that processing economies can be realized. Overcapacity may also spur the increased diversion for processing of by-catch and other marine organisms not intended for human consumption. Thus, the capacity of fishmeal and fish oil processing plant in Peru, which historically has complemented the rise of the anchovy fishery, may play a role in the web of pressures that drive an increased extraction of biomass from the sea, with resultant regional/local scale ecological changes.

11. Total toxic emissions to the ocean from the Peruvian fishmeal and fish oil processing industry

The release of toxic effluents into coastal environments may compromise the health of the marine ecosystems that support some of the domestic reduction and food fish fisheries in Peru. Toxic chemicals such as polybrominated diphenyl ethers (PBDEs) have been documented in farmed Atlantic salmon, and feed material from Chile has been implicated (Hites et al, 2004); thus, among other sources, there is a possible link to toxic emissions from Peruvian ocean or land-based industries.

12. Total fish exports (Peru), volume and value

Total fish export volume and value are noted as two distinct variables in Table 10. Peru exports the majority of its caught fish—anchovies and other reduction fish in the form of fishmeal and fish oil, and other fish and aquatic organisms for human consumption. The total quantity of fish available for consumption by Peruvians is strongly influenced by the total fish exports and the total fish imports into the country. For example, Peru exported 2,269,096 tonnes of fish in 2004 and imported 35,146 tonnes (WRI, 2006), although nearly 80% of the export volume was in the form of fishmeal or fish oil (USDA, 2004). Assuming (conservatively) that the exported fishmeal and fish oil were 90% anchovy content, Peru exported approximately 1,634,000 tonnes of (reduced) anchovy in 2004. The value of fish exports affects national wealth, especially in Peru where fish and fish product exports constitute a large share of total export earnings.

13. Total fish imports (Peru), volume and value

Total fish import volume and value are noted as two distinct variables in Table 10. These variables complement fish exports, and contribute to the total quantity of fish available for consumption by Peruvians. Virtually all fish imports to Peru (35,146 tonnes in 2004) are fish for human consumption, since domestic needs for fishmeal and fish oil are met by domestic production of these commodities. Since fish imports may come from anywhere in the world, imported fish will, to some extent, reflect changes in the marine or terrestrial ecosystems where the fish originated (for example, a drop in the TL of organisms living in those ecosystems, or the collapse of a fish population), and thus influence the quality of the fish available for consumption by Peruvians. If the ratio of value of fish imports to import volume is high (as compared to the ratio of the value of fish exports to export volume), this suggests something both about the quality of the imported and exported products and the global demand for them. In other words, the quality of the fish supply available for consumption by Peruvians may be more strongly influenced by the type of the fish being imported into Peru than by the type of fish being caught in Peruvian waters.

14. Species of fish exported and imported, and types of products

Gross domestic catch, import, and export data for fish, along with adjustments for expected losses during processing, storage, and preparation, tell us about the quantity of fish theoretically available for consumption by Peruvians. These data do not tell us about the quality of that fish. Also, gross data do little to suggest hypotheses about the ways that the Peruvian anchovy (and other) fisheries have affected the underlying ecosystem dynamics. It must be kept in mind that catch data from various fisheries are not the same as fish population survey data. Because the latter can be very difficult and costly to conduct, especially for some species, catch data are often used as late-warning signs of ecological change. However, experienced fishers do not always fish in the same location or at the same time, and national governments in charge of regulating fisheries provide incentives or disincentives for fishing in different ways and at different times. Thus catch data reflect not only something of the size of the underlying stock of fish but also the efforts applied by the fishers and the governance of the relevant regulatory bodies.

15. Total Peruvian fishmeal and fish oil exports

Both fishmeal and fish oil are currently demanded by the GFASI. As the David Suzuki Foundation (2002) points out, however, fish oil is the commodity that drives the reduction fish system. This is because a given quantity of reduction fish yields much less oil per unit weight than fishmeal, and because fish oil constitutes such a large proportion of farmed Atlantic salmon feed pellets (about 25% by weight, compared to 35% for fishmeal). The markets for fishmeal are generally more varied than for fish oil; of the total production of the latter, approximately 70% is consumed by the aquaculture sector and the farmed Atlantic salmon industry accounts for nearly 2/3 of that proportion (IFFO, 2002)--about 45% of the total world fish oil production. The volume of Peruvian fishmeal and fish oil exports provides a check on reduction fish catch data and thus indirectly on anchovy catch data, so long as the proportion of anchovies in the species mix that constitutes the fishmeal and fish oil being produced are known, as well as the amount of fishmeal and fish oil consumed domestically.

16. Mean trophic level (TL) of Peruvian marine fish catch

A decreasing TL is often an indicator of overfishing, and suggests that a variety of predator-prey relationships and energetic dynamics in an ecosystem are changing. A decreasing TL of fish caught in Peruvian waters may affect the quantity and quality of fish available for consumption by Peruvians, either in the short-term if the quantity and quality of imported fish does not compensate, or in the medium- and long-term if the phenomenon is global and imported fish cannot compensate for lost quantity and quality from domestic fisheries. Data on the mean TL of different Peruvian fisheries sectors (such as pelagic or demersal fish, or fish destined for reduction) would also be useful. Maintenance of TL in the regional ecosystem could be a goal, or marker, of sustainability in each fishery. Although further adaptation for this purpose would be needed, trophic flow models (e.g., Jarre-Teichmann, 1998) could be used to estimate the biomass of anchovy or other species which could be "predated" by humans in a given fishing season without decreasing the TL of the entire ecosystem.

5.3.1. Discussion of "buffer" variables which may obscure the proposed links between the Peruvian anchovy fishery and specific nutrition-related population health outcomes in Peru

The regional/local scale ecological changes of concern in this study are those which are caused or influenced by the Peruvian anchovy fishery and which affect directly or contribute to changes in the quantity and/or quality of fish available for consumption by Peruvians. Attempting to determine whether global scale or regional ecological changes caused or exacerbated by the GFASI have an impact on the quantity and/or quality of fish available to Peruvians requires meaningful data on the latter. Regional/local scale ecological changes directly affecting the quantity and/or quality of fish in the diets of Peruvians are conceivable only for a small set of circumstances, while the pathways and circumstances by which regional/local scale ecological changes could affect fish quantity and/or quality *indirectly* are many.

Direct influences would be seen most clearly in a non-money economy or one in which trade was extremely limited so that dependence on the productivity of regional/local ecosystems was very high, and negative feedback (e.g., a reduction in fish) would affect the consuming population immediately. Regional/local ecological changes induced by the Peruvian anchovy fishery (such as drop in the mean TL of organisms in the Peruvian marine ecosystem or a large drop in the anchovy population itself) could be buffered by the following variables.

The following set of variables should not be considered as an exhaustive list of the variables that are intermediate between regional/local scale ecological changes in Peru and the quantity and/or quality of fish available for consumption by Peruvians, but as illustrations of the types of mechanisms that are likely to influence the timing and strength of the influence of regional/local scale ecological change on basic indicators of the supply of fish for domestic consumption. All of these variables should be considered against the backdrop of an unbuffered situation where an ecological change such as a drop in the anchovy population leads directly to a concomitant drop in the quantity and/or quality of fish available for consumption by Peruvians.

1. Food aid to Peru from other countries or international organizations

Food aid from international donors rarely includes large amounts of fish (Barrett, 2002), but, in principle, food aid from other countries buffers the impact of any ecological conditions that might decrease fish availability by temporarily increasing the supply.

2. Gross Domestic Product (Purchasing Power Parity) *per capita*: Peru

Individual, household, and community income levels shape the choices available to people in the marketplace. If imported fish is readily available while domestic fish is declining in availability because of an ecological change, those with money to purchase the imported fish may realize no overall change in consumption level of fish. In addition, having money permits the purchase of domestic fish, which may have increased in price because of a drop in supply or a change in the exchange rates with the countries from which the imported fish originate.

As noted in the Introduction, Sieswerda et al's (2001) study showed that when GDP was introduced to models using measures of EI as independent variables and basic population health indicators as outcomes, it explained much more of the variation in the outcome measures than the EI variables, and the results were consistent in direction. In the present case study, it is unclear whether *per capita* purchasing power in international dollars, as a function of GDP, acts to mitigate, obscure, or simply prevent any nutrition-related health effects that might otherwise ensue subsequent to a reduction in the quantity or quality of fish available to the Peruvian population. In fact, greater purchasing power may act as a buffer either before or after the "exposure" that in Figure 13. we have called "Amount and/or quality of fish available for consumption by Peruvians." Greater purchasing power may enable either the purchase of imported fish, thereby making up for the volume or quality loss in fish produced domestically, or it may enable Peruvians to substitute other types of high quality protein into their diets, thereby preventing the health impacts hypothesized to be related to a reduction in the quantity or quality of fish available for consumption by them. This conjecture is limited to the aggregate, national scale and to the short-term time frame, where effects on sub-populations within Peru are unobservable, and where the presumed rationality of the GDP as a measure of long-term well-being or distributional justice is unquestioned. Other measures of monetary power are available, and GDP PPP *per capita*, which permits comparison across national currencies in terms of a predetermined hypothetical suite of goods and services to be purchased, may not be the one with the most explanatory power.

3. Population (Peru)

Regional/local scale ecological impacts that affect the quantity or quality of fish available for consumption by Peruvians is intuitively related to population size. The population of Peru is an important denominator in many of the variables proposed for consideration in this study, and also it may act as a buffer if a larger (or smaller) population permits better access to fish for consumption.

4. Urban population as a proportion of the total population (Peru)

The world is rapidly urbanizing, and Peru is not exempt from this process. Urban environments bring people into more frequent contact with imported goods, but modern cities in developing countries like Peru tend to be characterized by substantial income inequality. This means that some urban residents can take advantage of these goods and some cannot. As a buffering mechanism between ecological change that results in less, or lower quality fish from domestic sources and the amount or quality of fish that is available for consumption, the urban environment acts by concentrating resources, including imported goods. It would be expected that a society that is increasingly urban has greater access to imported goods, including (in this case) imported fish. However, we are not aware that this specific relationship has been tested. The social and economic features of increasing urbanization that affect actual access to specific goods like fish (whether physical or economic) must be explored in other studies, but the potential value of this dynamic to inform the generation of hypotheses merits its inclusion here.

5. Selected money flows in the GFASI and in Peru

The relationship between the anchovy fishery of Peru and the economic situation of individual anchovy fishers, the fishing industry as a whole (including processing for fishmeal and fish oil), the government of Peru, and the multinational companies involved in the GFASI is expected to substantially mediate or buffer the relationship between any ecological changes brought about by the Peruvian anchovy fishery and the effect of these ecological changes on the quantity and/or quality of fish available for consumption by Peruvians. For example, the Peruvian government has recently banned the use of sardines and mackerel for fishmeal and fish oil production in Peru, and has provided incentives to Peruvian fish processors to direct anchovies away from the export fishmeal/fish oil market and towards direct domestic consumption. This could increase the supply of small pelagic fish available for consumption by Peruvians, thereby contributing to an increase in the overall supply of fish available for consumption by Peruvians and reducing one of our exposures of interest.

5.3.2. Discussion of proximate exposure variables

In Figure 13., we propose that a change in the quantity or in the quality of the fish available for consumption by Peruvians (more accurately speaking, the quantity or quality of fish being consumed by Peruvians) explains some of the variation in basic nutrition-related disorders in the population. The several variables noted immediately above were discussed in their role as plausible modifying, or "buffering" factors that prevent a simplistic view of the way that regional/local ecological changes would affect the quantity or quality of fish available for consumption by Peruvians. The variables in this next group are proposed for consideration as measures of nutrition-related exposures that would reasonably be expected to contribute to nutrition-related disorders in the population. Consistent with the general proposition, the limit posed on these variables is that they are directly or indirectly related to either the quantity or quality of fish available for consumption by Peruvians.

The question of what constitutes the amount of fish and the quality of fish available for consumption by Peruvians must be answered adequately for sense to be made of the assertion that ecological changes experienced at the regional/local scale and driven either by regional/local scale or global processes, are affecting these variables. Estimates of total food supply in Peru, including components such as fish and fish products, are available from the FAO, as are descriptions of trends in the supply of foods from major dietary categories (again, supply is used as a proxy for consumption) such as cereal grains, legumes and nuts, fish, meat, and vegetables (FAO, 2000). More accurate information on actual consumption levels of specific foods like fish and fish products comes from methodologically sound household dietary surveys, but developing countries in particular often lack data at this level (Hels et al, 2003).

The amount and quality of fish actually consumed are the values relevant to any assessment of the relationship between fish intake and the prevalence of nutrition-related disorders in the population. Such data, which are derived from household dietary surveys, are not often available, so estimates of total food supply and total supply of particular food items serve as proxies for actual consumption. Information on total consumer expenditures on different fish products, coupled with accurate demographic statistics, could potentially fill the data gap; in addition, the following variables, for which data are available in at least some years, are first pass suggestions for further correlation analyses and hypothesis generation involving relationships between dietary fish intake and nutrition-related conditions.

1. Calorie supply per capita per day

Any change in the quantity of fish available for consumption will constitute a change in the total calorie supply per capita per day, provided there are no concurrent changes in the supply of any of the other types of food.

2. Calories per day from animal products (including fish)

This variable helps answer the question of whether an increase or decrease in fish consumption corresponds to a decrease in total calories from animal products, or whether there is an apparent substitution effect. This variable does not imply that there is a certain protein or nutritional content to the animal products represented by the aggregated data. It is also possible that a time trend towards a greater proportion of the diet constituted by animal products is associated with higher rates of risk factors and diseases of over-nutrition, such as obesity and CVD (WHO, 2003). This may depend on the particular types of animal products that are increasing in proportion in the diet; it also points to the possibility that changes in the total volume of animal products in the diet may overwhelm or obscure changes in the quantity or quality of fish consumption, even if the latter could be related to significant nutrition-related disorders with other variables being held constant.

3. *Per capita* food supply from fish and fishery products (Peru)

As noted above, this quantity refers to the food supply that is theoretically available for consumption, and should not be confused with the *per capita* food supply from fish and fishery products that is actually consumed. Again, reliable household level dietary survey data would be needed to determine this accurately. The quantity represented by this variable is the result of a calculation that takes into account domestic fish and fishery products production, export and import volumes for these goods, and corrections for known losses. The FAO indicates that this quantity is often used as a proxy for actual consumption of fish and fishery products.

4. Fish protein as a percentage of the total protein supply (Peru)
Like calories per day from animal products, this variable helps answer more directly the question of how one of the key nutritional benefits of fish (protein) fits into the overall diet. This variable does not, however, distinguish between types of fish protein (fattier and leaner sources, for example) and it does not directly provide information about the size of the total protein supply. A drop in the percentage of that total protein supply attributable to fish may signal a change in the factors that influence the supply of fish, or it may indicate changes in the factors that influence the supply of all sources of animal protein, all animal products, or the total food supply. Further data and more information on context are needed to resolve this question.

5. Quality of fish in total supply of food from fish and fish products
We found no sources of data on this variable. It may be possible to construct an index of fish quality based on known nutritional features (e.g., types and quantities of different fats in the flesh of the fish, levels of particular micronutrients known to be beneficial for humans) of the various species of marine organisms available for consumption, but this is beyond the reach of this study. The reasoning behind the construction and testing of this variable is that the protein, micronutrient, and contaminant (e.g., heavy metals, PCB) content of fish varies among species, and it may be that, for some mixes of species comprising the total fish component of the diet, the variation in nutritional content or contamination is great enough that some of the variation in consequent health outcomes would be explained by it.

5.3.3. Population health outcome variables

Part of the proposed causal web shown in Figure 13. is a series of health outcomes or impacts which might be expected if the quantity and/or quality of fish being consumed by Peruvians changes. The next several variables are proposed for consideration for future hypothesis testing. In fact, there are many possible nutrition-related health impacts that could be associated with changes in the quantity and/or quality of fish consumed by a population such as the total Peruvian population. Because many diets include complementary and nutritionally redundant foods, a change in the quality and/or quantity of fish being consumed may be a marker for other nutritional changes rather than a source of direct health harm or benefit. This is likely only to be seen in studies of many populations, and in comparisons of populations that have undergone similar changes with respect to a single dietary component but have realized significantly different health outcomes. For example, in developed, wealthy countries such as Canada, fish consumption has increased slowly (though erratically) since 1960 (FAO, 2006); however, overweight and obesity rates have also risen in the same period (Bélanger-Ducharme and Tremblay, 2005), suggesting that other nutritional (and non-nutritional) factors are at work. Although fish is generally seen as a good source of low-fat protein, at least in comparison with standard cuts of beef or pork, the increased consumption of fish may not actually be displacing other, calorie-dense foods.

Basic indicators of childhood malnutrition or under-nutrition, such as underweight (low weight for age), stunting (low height for age), and wasting (low weight for height) have not been linked in the scientific literature, to the knowledge of the author, either to the quantity of fish consumed or the quality of that fish, independent of other features of the diet. This makes suspect the proposition that reduced fish consumption or reduced quality of fish consumed in the diet will at some point be reflected in increased rates of basic nutrition-related disorders.

It is possible that the nutrition-related disorders associated with fish consumption may be disorders of over-nutrition, such as the obesity mentioned above. Again, the *per capita* consumption of fish may serve as a marker for other, more significant (from a health risk standpoint) changes in diet than it represents a health risk for malnutrition or under-nutrition *per se*; this remains to be determined. However, there is evidence that a diet rich in Omega-3 fatty acids, which are found in highest concentration in oily fish, may reduce the risk of heart attack (Harper and Jacobson, 2001). We know of no research showing the effects of limited Omega-3 fatty acid intake in populations that are not already at relatively high risk for heart disease, or which are dealing with the more chronic problems of malnutrition or under-nutrition.

Thus, the following health status variables should be understood as starting points for testing hypotheses generated from information derived from the case study, not as conclusively established outcomes of the exposure of interest; the strength of their association with fish quantity and quality variables will require further research to determine.

1. Under 5-years (Under 5) mortality rate (Peru)

Infant mortality is widely understood as a marker for overall maternal nutrition; under 5 mortality typically serves as a composite measure of the quality of the early childhood environment, including nutrition but also degree of exposure to infectious agents, access to timely health care and public health services, and physical safety. Because it is a measure of all-cause mortality, the under-5 mortality rate can be influenced by changes in risk factors not associated with nutrition; for this reason it must be interpreted carefully.

2. Prevalence of underweight in children under 5 years of age

Some chronic and infectious diseases, if endemic and highly prevalent, could be expected to be associated with a high prevalence of underweight in young children; however, as warning signs for malnutrition and/or under-nutrition, underweight, stunting, and wasting are reasonable outcome variables for hypothesis testing when outcomes linked with very specific exposures (such as to inadequate iodine or Vitamin C in the diet) are not appropriate.

3. Prevalence of stunting in children under 5 years of age

As above.

4. Prevalence of wasting in children under 5 years of age

As above.

5. Prevalence of overweight/obesity in adults

If incomes are high, alternative sources of protein are plentiful, and cultural preferences allow an easy substitution of one form of animal protein for another, then changes to the quantity or quality of the fish available for consumption by Peruvians might lead, in the case of a decrease in fish quantity, to an increase in the consumption of less lean sources of protein. Along with increased consumption of simple carbohydrates and of fats generally, this might be expected to contribute to an increased prevalence of overweight and/or obesity in the adult population, if other features of the population related to weight gain (e.g., activity level) remained constant. (Although not discussed here, prevalence data on multiple other diseases and disorders plausibly related to fish consumption could be used in investigations.)

Our propositional causal world suggests that the proximate or near proximate driver of reduced quantity and/or quality of fish available for consumption by Peruvians is ecological change for which the GFASI is in part responsible. However, this ecological change can be understood to be a result of drivers at two levels, the regional/local and the global. If only regional/local scale drivers of ecological change are active, then only domestic quantity and quality of fish would be expected to be affected. If global scale drivers are also active, then other ecosystems that sustain the fisheries that constitute the imported portion of the fish supply might also be affected. In the case of the GFASI, it may be impossible to pull apart these effects, but it is worth noting that the origin of the drivers of a regional/local level ecological change may tell us something about the likelihood of that change being more or less isolated from changes in other, similar ecosystems on earth. This in turn tells us something about which kinds of interventions are likely to be effective. Interventions dealing with regional/local scale drivers of ecological change may not be adequate if global drivers of ecosystem change at the regional/local level also are involved.

Table 11. provides a sample of plausible direct and indirect ways in which regional ecological changes could affect the amount or quality of fish available for consumption by Peruvians, which could then affect the prevalence of nutrition-related disorders in the Peruvian population.

Table 11. Example scenarios using variables from Table 10.

Causal scenario	Relevant variables	Peruvian sub-population affected (mechanism of action)	(Selection of) key assumptions
1. Changes in marine ecology result in fewer fish caught per unit of effort; total volume of fish available for consumption in Peru decreases	Total marine catch (Peru); Total fish catch, marine and inland (Peru); Population (Peru); Fish protein as percentage of total protein supply	Subsistence fishers and those who rely on their provision (smaller volume of fish caught)	No foreign trade; all fish consumed in Peru is caught in Peruvian waters; no fish caught in Peruvian waters are exported; no technological improvements in fishing technique over time
2. Changes in marine ecology increase abundance of anchovy f/export earnings increase/income inequality in Peru increases/domestic prices of fish increase of greater purchasing power of upper income groups and demand inelasticity	Total annual catch of anchovy (Peru); Total exports of Peruvian fishmeal and fish oil; Selected GFASI-related money flows; GINI (Peru); Proportion of food budget used to purchase fish (with reference to pre-GFASI baseline year)	Urban poor (fish priced out of reach)	No domestic policies counteract processes by which income inequality increases; demand for fishmeal from GFASI is inelastic; Peruvian market is not concurrently inundated with cheap foreign fish

Causal scenario	**Relevant variables**	**Peruvian sub-population affected (mechanism of action)**	**(Selection of) key assumptions**
3.Changes in ecology decrease size of anchovy catch/decreased anchovy catch results in decreased fishmeal and fish oil exports and decreased income from foreign trade/decreased income means less tax money to Peruvian government/less tax money means decreased expenditure on transportation infrastructure in rural areas	Total exports of Peruvian fishmeal and fish oil; Total exports of Peruvian fishmeal and fish oil (value in relevant currencies); Selected GFASI-related money flows; Proportion of population in urban areas (Peru)	Rural communities (distance from or access to consistently supplied marketplace)	Fishmeal export earnings are related to budget available to the Peruvian government with which to improve or build roads and other domestic transportation infrastructure; public transportation infrastructure is a key factor in determining whether rural subpopulations are able to get to market to buy fish

5.4. Estimation of the EF of the GFASI

In sections 2.4. to 2.4.4. in Chapter 2, we discussed the context in which regional/local scale drivers of marine ecological change in Peru are likely to impact population health in that country. Table 11. suggested some ways that pressures from the Peruvian anchovy fishery or from global scale drivers might affect the regional/local marine ecology, and how, in turn, these changes might affect population health. This present section estimates the EF of the GFASI for the year 2004. It then discusses how the GFASI's impact on global scale drivers of ecological change, such as climate change, could ultimately impact regional/local scale ecosystems important to the Peruvian food supply. Through pathways described in Figure 13., those changes are proposed to have specific population health implications for Peruvians.

Tyedmers' (2000) EF analysis showed that more than 99% of the marine ecosystem area required to support Atlantic salmon cultivation in British Columbia (BC) was dedicated to the production of fishmeal and fish oil, the main material inputs into farmed Atlantic salmon production. More specifically, this marine ecosystem area is the estimated area (5.6 gha per tonne of Atlantic salmon produced) required to support the aquatic organisms (such as anchovy) used in the farmed Atlantic salmon feed. Additionally, greater than 90% of the industrial energy investment for Atlantic salmon cultivation in BC was determined to be associated with feed pellet production. Tyedmers estimated that 3,325 kg of CO_2 were emitted per tonne of farmed salmon feed produced, which, for the feed conversion ratio of 1.7:1 assumed in that study, would translate into approximately 5,650 tonnes of CO_2 emitted per tonne of farmed Atlantic salmon produced.

The relative consistency of salmon feed pellet composition across the GFASI suggests that differences among countries in energy consumption, and thus in EF per unit of Atlantic salmon produced, are likely to be small. However, Table 12. below is included for the purpose of illustrating an additional analytical step which could improve the accuracy of the estimation of the EF for the GFASI. Table 12. also shows how the nature of the energy sources used by an industry might affect its contribution to ecological change (and any related human health impacts) via emission of greenhouse gases that contribute to global warming. Table 12. consolidates data on the national mix of energy sources for each of the major farmed Atlantic salmon producing countries in 2004. The large majority of the energy consumed in farmed Atlantic salmon production is devoted to the fishing effort expended for catching and processing the fish used for fishmeal and fish oil. Thus, even large differences in the proportion of national energy derived from low-greenhouse gas (GHG) emitting sources in producer countries are not expected to significantly affect the overall EF of the GFASI. However, it should be noted that for some other types of industries where the point of final production is the main site of energy consumption, differences in energy sources would be important for estimating some kinds of ecological impacts.

Table 12. Energy consumption by source (percentage), farmed Atlantic salmon producing countries

Data Sources:

World Resources Institute (WRI): 1999
Energy Information Administration (EIA), United States: 2003, 2004
International Atomic Energy Agency (IAEA), Austria: 2006
All percentages are approximate and may not total 100%

Country (Data source)	Oil	Gas	Coal	Nuclear	Hydro	Renew-ables	Approximate proportion of low GHG emission sources[1]
Canada (EIA)	32	24	12	6	25	1	.32
Norway (EIA)	27	8	2	0	60	0	.60
USA (EIA)	40	23	22	8	3	1	.12
Chile (EIA)	42	23	10	0	22	1	.23
Finland (WRI)	36	10	16	19	0	19	.38
Portugal (WRI)	65	10	19	0	2	5	.07
Greece (EIA)	62	7	26	0	3	1	.04
Russia (EIA)	19	53	16	5	6	0	.11
Denmark (WRI)	45	20	25	0	0	5	.05
Cyprus (WRI)	100	0	0	0	0	0	0
UK (EIA)	35	34	16	11	0	1	.12
Faeroe Islands (No data available)	--	--	--	--	--	--	
Ireland (WRI)	35	35	30	0	0	0	0
Australia (EIA)	34	17	44	0	3	1	.04
Iceland (WRI)	33	0	0	0	0	67	.67
France (EIA)	38	14	4	39	5	0	.44
Spain (WRI)	52	10	18	14	2	3	.19
Turkey (EIA)	39	23	25	0	13	0	.13
Sweden (WRI)	33	2	5	35	11	15	.61

[1] For our purposes, "Low greenhouse gas (GHG) emission sources are: hydro, nuclear, and renewables (wind, geothermal, solar, etc.).

Table 13. below provides a framework for documenting information on the sources of the feed material, and the sources of the Peruvian anchovy-based fishmeal and fish oil constituents of that feed material, used by producers of farmed Atlantic salmon. It was beyond the resources of this study to obtain information for most of the cells. However, Table 13., like Table 12., is included here as an example of a tool that could be used in a more focused exploration of the EF of the GFASI than the one provided in this study.

Table 13. Details on fishmeal, fish oil, and feed pellet sourcing and composition, by GFASI producer country

GFASI country (in order of 2004 production volume	**Fishmeal and Fish Oil Purchased from (country(s) and company(s))**	**Peruvian anchovy content (percentage) of fishmeal and fish oil**	**Feed pellets purchased from (country(s) and company(s)):**	**Notes**
Norway	Norway (majority)	Not determined	Not determined	
Chile	Chile (majority)	Not determined	Not determined	Anchovies fished from ecosystem overlapping that exploited by the Peruvian fishery
UK	Peru, Chile	Not determined	95% from UK companies: BioMar Ltd., EWOS Ltd., Trouw Aquaculture	
Canada	Canada, Peru (Tyedmers, 2000)	Not determined; unofficial sources suggest nearly 100% in recent years	Majority from Canada	
Faeroe Islands	Not determined	Not determined	Not determined	
Australia	Not determined	Not determined	Not determined	
Ireland	Not determined	Not determined	Not determined	

GFASI country (in order of 2004 production volume	**Fishmeal and Fish Oil Purchased from (country(s) and company(s))**	**Peruvian anchovy content (percentage) of fishmeal and fish oil**	**Feed pellets purchased from (country(s) and company(s)):**	**Notes**
USA	Not determined	Not determined	Not determined	
Iceland	Iceland (majority)	Not determined	Not determined	
France	Not determined	Not determined	Not determined	
Russia	Not determined	Not determined	Not determined	
Spain	Not determined	Not determined	Not determined	
Greece	Not determined	Not determined	Not determined	
Denmark	Not determined	Not determined	Not determined	

Table 14. below includes the basic data used to calculate the total EF of the GFASI for 2004, as well as the result of that calculation. Several columns are included in Table 14. for the purpose of making relevant adjustments for each producer country, mainly based on differences in energy demands which may exist among these countries. No adjustments were actually made for our calculations, an approach which is justified in Table 15.

Table 14. Calculation of ecological footprint of GFASI in 2004

Country	2004 farmed Atlantic salmon production (tonnes)	Global hectares required per tonne of farmed Atlantic salmon production (from Tyedmers, 2000): per tonne EF[1]	Unadjusted total EF for 2004 production of farmed Atlantic salmon[2]	Adjustment for variation in energy demand (fishing effort) (Tyedmers, 2000 = reference = 1)[3]	Adjustment for variation in energy demand (process used to manufacture fishmeal and fish oil) (Tyedmers, 2000 = reference = 1)[4]	Adjustment for variation in energy demand (transportation used to deliver fishmeal and fish oil, and energy requirements for non-fishmeal and fish oil ingredients in feed pellets) (Tyedmers, 2000 = reference = 1)[5]	Adjusted total EF for 2004 production of farmed Atlantic salmon
Chile	565,902	Marine hectares: 9.91; Terrestrial hectares: 2.84; Total = 12.75	7,215,250.5				7,215,250.5
Norway	349,329	12.75	4,453,944.75	1.0	1.0	1.0	4,453,944.75
UK	158,099	12.75	2,015,762.25	1.0	1.0	1.0	2,015,762.25
Canada	82,374	12.75	1,050,268.5	1.0	1.0[6]	1.0	1,050,268.5
Faeroe Islands	37,296	12.75	475,524	1.0	1.0	1.0	475,524
Australia	15,127	12.75	192,869.25	1.0	1.0	1.0	192,869.25
Ireland	14,828	12.75	189,057	1.0	1.0	1.0	189,057
USA	14,067	12.75	179,354.25	1.0	1.0	1.0	179,354.25
Iceland	6,624	12.75	84,456	1.0	1.0	1.0	84,456
France	735	12.75	9371.25	1.0	1.0	1.0	9371.25
Russia	203	12.75	2588.25	1.0	1.0	1.0	2588.25
Spain	30	12.75	382.5	1.0	1.0	1.0	382.5
Greece	16	12.75	204	1.0	1.0	1.0	204
Denmark	7	12.75	89.25	1.0	1.0	1.0	89.25
TOTALS	**1,244,637**	12.75	**15,869,121.75**				**15,869,121.75**

1 For simplicity, the total global hectares (terrestrial plus marine) are provided. Marine hectares, which are appropriated almost totally by the salmon feed sub-system of the total Atlantic salmon farming enterprise, are based on the net primary productivities of the actual ecosystems from which the various reduction fish species assumed in Tyedmers' analysis were fished.

2 The unadjusted total EF assumes that all the farmed Atlantic salmon operations in the producing countries have the same material and energetic demands as the BC farmed Atlantic salmon industry studied by Tyedmers (2000).

3 Because the fish species used to produce fishmeal and fish oil vary, some differences in fishing effort (and thus in total energy required for a given amount of production) are expected among countries.

4 Only sources of energy for producing electricity for plant operations were considered; adjustments were proposed based on comparison of the national mix of energy sources to the reference mix (British Columbia). However, energy land required to assimilate carbon emissions from energy production associated with the electricity used in farmed Atlantic salmon production accounts for approximately 2% of the total energy land "counted" for the growing of farmed Atlantic salmon; therefore, even countries using national energy sources for electricity generation that were different (in terms of the renewable/non-renewable mix of sources) from that of Canada would not contribute to a significant difference in the area of energy land required for the amount of electricity used in the production of fish and fish meal.

5 Farmed Atlantic salmon feed pellet composition is assumed to contain livestock meal at about 10% of the total, and grain crop inputs at about 30% of the total pellet mass. Fishmeal and fish oil was assumed to constitute the remainder (60%) of the pellet mass. These proportions approximate those stated or estimated by Tyedmers (2000).

6 Reference value.

Table 15. mentions several factors potentially influencing the EF of specific producer nations of the GFASI, reasons for concern that these factors might influence the outcome of EFA, and justifications for assuming approximate equivalency in energy consumption among farmed Atlantic salmon producer nations.

Table 15. Country-specific variables influencing EF of GFASI

Factor Influencing EF	**Reason for Concern**	**Justification for Assuming Equivalency Across Producing Countries**
1. Geographic origin of fishmeal and fish oil component of feed	Some GFASI producers (e.g., Norway) use fish meal and fish oil produced domestically; others import fish meal and fish oil from sources 000's of km away	Energy consumption involved in transporting fishmeal and fish oil feed constituents to end-users comprises < 2% of total industrial energy inputs per tonne of Atlantic farmed salmon produced (Tyedmers, 2000)
2. Type of fishing technology, distance to fishing grounds, level of certainty around stock location (fish catch per unit of effort)	Wide variation exists in fish catch per unit of effort for different technologies, fleets, and fisheries	Data not obtained
3. Transportation of non-fish components of feed to grow-out operations	As with fishmeal and fish oil, some GFASI producer countries use domestic resources while other rely on imports from a distance (Government of Scotland, 2006)	Variation between countries assumed small; contribution to overall industrial energy inputs for farmed Atlantic salmon production is small
4. Technology employed in fishmeal and fish oil plants	Variation in technology employed in plants historically has meant moderate variation in energy input per tonne of fishmeal or fish oil produced (Tyedmers, 2000)	Data not obtained on all plants producing fishmeal and fish oil consumed by the GFASI

Factor Influencing EF	**Reason for Concern**	**Justification for Assuming Equivalency Across Producing Countries**
5. Species of farmed salmon produced	Chinook salmon may require nearly 40% more feed per kg of finished product than Atlantic salmon (Tyedmers, 2000)	This study focuses on Atlantic farmed salmon production only; feed conversion ratio assumed constant regardless of producing nation
6. Energy sources used to produce electricity for grow-out operations	GFASI producer countries utilize different mixes of energy sources to produce electricity; some sources do not generate CO_2 and thus less "energy land" would be incorporated into the EF for that country's farmed Atlantic salmon production (IAEA, 2006; US Energy Information Administration, 2003; WRI, 1999)	Energy used to produce electricity for grow-out operations constitutes a small portion of the total industrial energy inputs into the production of Atlantic farmed salmon (Tyedmers, 2000)
7. Differences in technology in grow-out operations	Business incentive to move towards most efficient technology suggests differences between GFASI producer nations, especially since industry is relatively young	Spread and adoption of new technologies among producing countries is assumed to be rapid

Based on the 2004 production of farmed Atlantic salmon by producer countries for which data are available, the GFASI requires **15,869,121.75** gha of ecological space to support one year's production of farmed Atlantic salmon. For the calculations and discussion that follow, we will use the round figure of 16,000,000 gha.

According to The World Wide Fund for Nature (2003), which uses data endorsed by the Global Footprint Network (Oakland, CA), based on world-average productivity, there are approximately 11.2 billion global hectares of bioproductive land and water area on Earth. Approximately 80% of this area is land area and about 20% is water area—mainly productive marine upwelling ecosystems such as the HCUE. Based on these figures, the demand placed on Earth's biocapacity by the 2004 production of farmed Atlantic salmon would be 16,000,000 ha/11,200,000,000 ha, or approximately 1/700th of the total bioproductive space available. If 10% of Earth's bioproductive space is set aside as non-negotiable wilderness area so that the populations and gene pools of other species are protected and so that human benefits flowing from biodiversity can be preserved, the proportion of bioproductive land and water area appropriated by the 2004 production of farmed Atlantic salmon would be approximately 16,000,000 ha/10,080,000,000 or about 1/630th of the total bioproductive space available. Further analysis of this fraction into bioproductive terrestrial and marine components was not explored in this study.

5.4.1. Interpreting the EF of the global farmed Atlantic salmon industry

Two key questions are posed by the result obtained in the calculation of the EF of the GFASI: (1) Is this number accurate, and is it valid?; and (2) How should it be interpreted from an epidemiological perspective? This section will deal briefly with the first question and at greater length with the second.

5.4.2. Accuracy and validity

The accuracy of the number for the GFASI's EF depends on the rigour of the method developed by Tyedmers (2000) to calculate the EF for the production of farmed Atlantic salmon in British Columbia in 2000, and secondarily on the accuracy of the farmed Atlantic salmon production figures maintained by the FAO. The content validity of the number depends on the ecological theory and assumptions underpinning Ecological Footprint Analysis.

Tyedmers' method has not been criticized in the peer-reviewed academic literature. The complexity of the task of accounting for all major energetic and material inputs to both the wild salmon fishery and the farmed salmon fishery of British Columbia, in combination with the lack of easily accessible data on several elements of the system, required making numerous assumptions. These were well defended, however, and most of the assumptions would have the effect of underestimating the EF. For example, components of the farmed salmon feed derived from livestock meals (bone, meat, and feather) were assumed to be derived entirely of chicken fed only with grain corn. Because a lower feed-to-protein biomass ratio obtains in chicken production as compared to beef or pork production, and because corn has a higher per-acre protein yield than other grain crops like wheat, in Tyedmers' calculations the EF of the "terrestrial livestock" component of farmed salmon feed is likely to under-estimate the actual area of terrestrial cropland required. Similarly, relatively efficient fishing technology (which means less "energy land" consumed per unit production) was assumed in Tyedmers' calculations of the catch effort required for the reduction fish used for fishmeal and fish oil production. It is assumed, as a result, that the EF required to produce a tonne of farmed Atlantic salmon in British Columbia is an underestimate of the actual demands on the ecosphere.

FAO data on farmed Atlantic salmon production worldwide are considered reliable, but they depend on consistency and accuracy of reporting by national governments, which in turn depend on accurate reporting by the farmed salmon industry in each country. Serious concerns have been raised about the accuracy of wild fish catch reporting at the national level, especially in China (Watson and Pauly, 2001), but we could find no reason not to treat the FAO figures for farmed Atlantic salmon production as accurate. Most of the discussion and analysis in the present research does not require extreme accuracy of production data.

At the completion of this study, data were not yet available on the global production volume of farmed Atlantic salmon in 2005. However, production data from 1994 through 2004 can be used to establish the average percent increase over each of the yearly intervals in the period. Thus, in 2005, a 12% increase in production over the 2004 level is predicted (FishStat, 2004). The amount of bioproductive land required to produce a tonne of farmed Atlantic salmon was assumed constant for the EF calculation; thus, an increase of 12.5% in 2005 over 2004 represents a corresponding increase of 12.5 % in the EF of the industry for 2005. Theoretically, estimations of the size of the EF of the GFASI could be projected into the future and qualified by estimates of trends in other, related industries such as the Peruvian anchovy fishery, and by relying on projections, among other things, of demand for farmed Atlantic salmon products in the future. It is beyond the scope of this study to model the GFASI in terms of the gross size of its future demand on Earth's bioproductive foundations. However, assuming a moderate annual growth rate of production of 2.5% from 2005 to 2020, and assuming that the specific marine and terrestrial ecosystems on Earth (upon which the GFASI relies for the provision of the goods and services necessary for the industry) could support this growth, in 2020 the GFASI's yearly production would be just over 2.0 million tonnes, corresponding to an EF for the industry that would be more than 50% greater than the current area.

As noted in the Introduction section, concerns have been expressed with the ecological assumptions underlying EFA. One of the concerns of particular relevance to the present study is that the EF does not allow for trade-offs among the three classic dimensions of evaluation under the ecological economic paradigm: efficiency, equity, and sustainability (van den Bergh and Verbruggen, 1999). In the estimation of the EF of the GFASI in this study, this restriction implies the assumption that the only value being considered is sustainability: is the enterprise viable into the foreseeable future, given the relationship between the known or anticipated ecological requirements of the enterprise and the ecological goods and services available to it? While issues of efficiency and equity are not directly addressed by the aggregate EF value for the GFASI, neither, strictly speaking, can conclusions about the sustainability of the industry be made without reference to the other enterprises in which humans are engaging at the same time. The EF of the GFASI is an aggregate measure, but it provides a means of comparing the net ecological costs of producing a certain suite of population health impacts through the production of farmed Atlantic salmon versus the production of that same suite of population health impacts via some other means—for example, through catching wild salmon or producing dietary supplements. This is an efficiency question. Because the GFASI is one part of the world economy and not the whole, the specific distribution of the suite of population health impacts, and the distribution of the ecological costs of producing them, brings the issue of equity into view. These concerns are, in part, epidemiological concerns, and are explored in the following section. The research question requires looking at how the (un)sustainability and the (in)equity of the GFASI might be impacting the quantity and/or quality of fish in the diets of Peruvians, and as a result and by implication, whether the GFASI contributes to nutrition-related disorders in Peru.

5.4.3. Epidemiological interpretation

The remainder of this section and the section following imply that the ecological impacts that flow from the operation of the GFASI can be categorized as either on the "global" or "regional/local" scale. However, this distinction should be understood as having to do with the level at which the drivers of ecological change operate, not with the level at which the ecological changes themselves are actually experienced by human beings. The warming of the global climate provides an example of this distinction in meaning. Human activities contribute carbon to the atmosphere, in the form of CO_2 and other gasses, in excess of what can be absorbed by the world's carbon sinks. This results in a build up of greenhouse gasses in the atmosphere, which leads to a warmer planet. The degree of warming experienced at a given locale on Earth will vary, but on average, current estimates are that mean global temperature will increase between 2.0 and 4.5 degrees Celsius over the next century (IPCC, 2007 unpublished). For humans living in a particular region and dependent on the ecosystem goods or services from that region and from other regions (a suite of ecosystems that we can call "S"), the population health implications of the global change driver (i.e., warmer average temperature virtually everywhere on Earth) will be experienced via change in the ability of "S" to provide goods and services that support the health of the specific population in question. Except for likely increases in direct, heat-related mortality—and even those increases are experienced through warmer local weather, not global climate *per se*—the human health consequences of a warmer global climate will be mediated through changes in the specific ecological systems that provide goods and services for the meeting of basic human needs. The consequences will also be mediated through changes in the infrastructure and technologies that humans use to transform ecosystem goods and services into lifestyle supports, and in the flows of money that will change in response, for example, to changes in the resource base, to overburdened infrastructure, and to extreme weather events.

The distinction between global and regional/local drivers of regional/local level ecological changes is often made in the sections following because it suggests that making effective changes in the ecological impacts of the GFASI may require interventions at different political levels and/or in different sectors. For purposes of the following analysis, "global scale ecological impacts" and "regional/local scale ecological impacts" are defined as follows:

Global scale ecological impacts: Changes in ecosystems at various scales, including the regional/local scale, which are caused by changes in parameters of the ecosphere itself.

Regional/local scale ecological impacts: Changes to ecosystems at the regional/local scale which are caused by pressures exerted directly on those ecosystems. This does not exclude the possibility that changes to these ecosystems may eventually cause changes to the parameters of the ecosphere, nor that regional/local level drivers may be (as one possibility) intensified by global-scale drivers.

The GFASI contributes to ecological impacts at both scales. This section discusses some of the epidemiological implications of the GFASI's global scale ecological impacts in light of the EF of the whole industry.

The unique eco-epidemiological concern with unsustainable human enterprises has to do with the potential population health consequences of undermining the ecosphere's life-support systems. The consequences are expected to be both direct (e.g., fewer edible fish in the oceans as a consequence of unsustainable rates of fishing—see Worm et al, 2006) and indirect, as a result of loss or degradation of the ecological capital that is transformed to create manufactured goods and, as a result, that helps produce health-protective social goods like employment and household income. As noted above, the GFASI's EF in 2004 does not tell us anything directly about its sustainability as a single industry, because we do not know how inflexible the other industries of the world are in terms of their ecological footprints, and we do not know how strong are the pressures that push the

GFASI to grow in the future, and thus we do not know how large its EF might eventually become. We also do not have clear measures of the sustainability of all of the actual ecosystems upon which the GFASI depends. We know, based on Tyedmers (2000), that as a whole the EF of the GFASI is likely greater than the EF of the wild salmon fishery, were the latter to produce the same volume of fish. We know that the operation of the GFASI increases entropy in the macro-system, since non-renewable energy sources are utilized and because no carbon sinks are simultaneously being created to offset the amount of "energy land" demanded by EF analysis to absorb the products of combustion. But we also know that the EF value for the GFASI tells us nothing about the likelihood or location of global scale ecological system stresses or collapses associated with its operation, nor about the human health implications of those ecological impacts. The aggregate EF for the GFASI does not say anything about the equity of the distribution of the health impacts that it may lead to because of the changes it induces in the ecosphere; we do not know who is reaping the population health benefits of the GFASI's operation and who is incurring (or will incur) the risks and harms associated with the enterprise if or when the global scale ecological changes to which it contributes result in population health impacts.

This study is concerned about presenting the issues that must be considered in order to answer the question of whether, and if so, how, ecological changes to which the GFASI contributes are connected to the generation of specific exposures which may be associated with several nutrition-related disorders in Peru. The population health impacts of the global scale ecological impacts discussed in this section may be distributed widely in space and time; however, it is those impacts realized by citizens and residents of Peru with which we are concerned. As such, the question of the population health implications of the sustainability (or unsustainability) of the GFASI should be understood as follows: what impact would an unsustainable GFASI be likely to have on the exposures of interest in our propositional causal web—i.e., changes in the quantity and/or quality of fish available for consumption by Peruvians?

Whether or not a GFASI EF of 16,000,000 global hectares is unsustainable, and, if so, how unsustainable, depends on the relationship between it and the multiple other human enterprises that constitute the global economy. It also depends on whether any of the specific ecosystems upon which the industry depends are in fact being utilized unsustainably, given the size and the distribution of current and future demand for farmed Atlantic salmon. Table 16. highlights key dynamics that affect the GFASI's contribution to global scale ecological changes and the anticipated population health impacts of those changes. It should be kept in mind that the focus here is mainly on developing a better understanding of the system within which the standard epidemiological questions about the types and distributions of morbidity and mortality, and their causes, may be investigated.

Table 16. Factors influencing GFASI impact on population health via global-scale drivers of ecological change

Specific Amplifying/Mitigating, or Buffering dynamic[1]	**Amplifying/Mitigating, Buffering, or Uncertain?**[2]	**Probable mechanism(s) of influence**	**Documentation of anticipated trend (if available)**
1. Expansion of production (volume)	Amplifying	Increase in GHG emissions from fossil fuel combustion (global warming); increased pressure on wild fisheries (change in productivity/trophic structure of marine ecosystems)	(Delgado et al, 2003)
Population growth (global)	Uncertain	Larger market, leading to expansion of production (1.) (see ecological impacts for 1.); smaller market resulting from increased demand for alternative uses of GFASI inputs (diminishment of impacts associated with 1.)	
Change in number of firms in industry	Uncertain	Mechanism of action similar to (1.), except that the size of the impact will be influenced by the global distribution of firms and the "vertical integration" (e.g., with the various input industries) of those firms	(Intrafish, 2006a)

Specific Amplifying/Mitigating, or Buffering dynamic[1]	**Amplifying/Mitigating, Buffering, or Uncertain?**[2]	**Probable mechanism(s) of influence**	**Documentation of anticipated trend (if available)**
Increased price of inputs to GFASI (e.g., fishmeal and fish oil, energy)	Uncertain	Expansion or reduction of production, depending in part on management regime for reduction fishery and price of farmed Atlantic salmon (mechanisms of action similar to 1.)	(OECD, 2003; Hannesson, 2003)
Increased price of product (farmed Atlantic salmon)	Uncertain	As immediately above	(OECD, 2003)
Change in price of close substitutes (i.e., wild salmon): cross price elasticity of demand	Uncertain	Increase or decrease in GFASI production, acting through same mechanisms as (1.)	(Willmann, 2005)
Change in price of functional substitutes (e.g., sources of meat protein)	Uncertain	As immediately above	

Specific Amplifying/Mitigating, or Buffering dynamic[1]	**Amplifying/Mitigating, Buffering, or Uncertain?**[2]	**Probable mechanism(s) of influence**	**Documentation of anticipated trend (if available)**
Changes in feeding technology (i.e., feeding efficiency)	Uncertain	Expanded production (and impacts via the mechanisms described in 1.) may result from increased feeding efficiency, since costs of production will have been lowered, making increased production more profitable; other consequences are possible, depending on production decisions after efficiency improvements and the entry of new producers into the industry	
Change in feed ingredients (e.g., substitution of grain-based meals and oils for fishmeal and fish oils)	Uncertain	Expansion or decrease in production, with associated impacts as described in (1.)	(OECD, 2003; Willmann, 2005)

[1] Operational definitions are as follows:

> Amplifying/Mitigating: tending to increase (Amplifying) or decrease (Mitigating) the size of the GFASI's impact on global scale ecological change.
>
> Buffering: deferring, in time or space, the GFASI's impact on global scale ecological change.
>
> Uncertain: influence on GFASI is uncertain, though impact of some kind is considered likely.

[2] The influence of any of the factors listed in this table is only independent by degree of the influence of the other factors; for illustrative purposes, the statements made about the action of each dynamic (amplifying, mitigating, or buffering) assume that the other dynamics are held constant.

Table 16. shows that the impact of changes in most of the influential factors listed is uncertain. The price of relevant goods (the product, the inputs, competing and complementary goods) are of course very influential to decisions that individual producers make about expanding or reducing production of farmed Atlantic salmon. Virtually all the factors noted in Table 16. have their effect by stimulating an increase or a decrease in the production volume of farmed Atlantic salmon. The volume of production is directly related to the EF of the industry, given prevailing technology and input characteristics. With changes in technology and input characteristics (e.g., more efficient feeding and less fishmeal and fish oil in the feed), a constant level of production might result in a smaller EF for the GFASI. However, this too is uncertain because of the multiple dynamics relevant to the outcome.

As noted earlier, without trade in ecological capital, sustainability for most industries would be a regional issue, since the opportunity to exploit resources on a global scale would be impossible. Negative ecological feedback at the regional level (e.g., depletion of needed natural resources or overwhelm of the region's capacity to assimilate waste) would be self-correcting and limit the size of the industry, in the long term, to a sustainable size—or else the lack of resources at the regional scale would undermine the industry.

A different, but related, question to that of the GFASI's sustainability is the question of whether the service that the GFASI provides to humans (namely, providing a source of high-quality dietary protein) is accomplished more efficiently by the GFASI than by other means of providing this same service. Different definitions of the product of the GFASI would suggest different industries for comparison. For example, a narrow definition of the GAFSI's product would be "Atlantic salmon," while a broader definition would be "high-quality protein." If all high-quality protein sources are indeed fully substitutable to the populations consuming them, then it would be fair to compare the aggregate EF of the GFASI with that of other industries such as those producing terrestrial livestock, eggs, or soy (whatever ones' definition of "high-quality protein" happens to be), in order to determine which way of meeting the population's nutritional needs or preferences would be most ecologically efficient. If the narrow definition is used, then the obvious comparison industries are the wild Atlantic or Pacific salmon industries. In fact, Tyedmers' (2000) study, which provided the basis for our calculation of the EF of the GFASI in 2004, did compare the EF of producing a tonne of farmed Atlantic salmon in BC with that of producing close substitutes such as farmed chinook salmon and commercially caught sockeye and pink salmon. Tyedmers found that producing a tonne of commercially caught pink salmon resulted in the smallest EF, and thus, by this measure, it was the most ecologically efficient means of producing salmon. However, the volume of pink salmon which could be produced yearly would be too small to meet the global demand for salmon, so other less efficient (but less naturally constrained, at least in the short term) means of producing salmon would have to be introduced into the mix of production.

The next section looks briefly at the issue of the GFASI's place in the entire world food system.

5.4.4. The GFASI and the world food system

In 2003, total world food production, including fishing, growing crops, and raising animals for food, appropriated approximately 53% of the total global supply (11.2 billion global hectares) of bioproductive land and water area, with no provision for wilderness (World Wide Fund for Nature, 2006). Assuming that the EF of world food production in 2003 was very close to that of 2004, the GFASI appropriated approximately 0.27 percent, or about 1/370th, of Earth's biocapacity devoted to food production. Although the question of whether this proportion is ethically and strategically defensible, given the global population's food needs, is a critical question for international population health, this question is beyond the scope of this study. Our present focus on the potential population health implications for Peruvians of the GFASI's global scale impacts suggests the following question:

Does that proportion of Earth's food production capacity appropriated by the GFASI act through global-scale mechanisms to reduce the food production capacity of the specific ecosystems upon which Peruvians depend for a fish supply of sufficient quantity and/or quality? If so, how?

The question immediately above asks whether the GFASI's contribution to changes in the parameters of the ecosphere affects, via changes to the relevant regional/local scale ecosystem(s), the quantity and/or quality of fish available for consumption by Peruvians. Providing a complete answer to this question is beyond the scope of this study, but the following discussion set the question in context. Also, from what is known about the relatively small role of fish in the overall Peruvian diet (Table 7. suggests about 1% in total calorie terms, and the discussion in section 2.4.2. indicates that fish constitutes about 9% of total protein intake), the implications for nutrition-related risks are uncertain. This is not to say that such risks would not be substantial for particular Peruvian subpopulations dependent on fish for sustenance or livelihood.

The GFASI's primary contribution to global-scale change is likely through its consumption of carbon-based fuels and the emission of carbon dioxide. Thus, its primary contribution to any important regional/local scale ecological changes in/near Peru that are induced by global drivers is likely to be its contribution to global warming. Table 17. shows how a warmer climate could affect regional/local ecosystems that provide goods and services which in turn affect the quantity and/or quality of fish available for consumption in Peru. In line with the propositional causal web shown in Figure 13., the implications for the quantity and/or quality of fish available for consumption in Peru are explained through their relationship to changes in the marine, and possibly terrestrial, ecosystems that support those fish species which are fished domestically in Peru and that become part of the domestic fish supply. These impacts do not necessarily have to run through the Peruvian anchovy fishery.

There may be other ways in which global warming (again, a phenomenon to which the GFASI contributes) impacts or could impact the fish food variables of interest in this study. For example, based on the values of approximately 5650 kg of CO_2 emitted for every tonne of farmed Atlantic salmon produced (estimated from Tyedmers, 2000), and a

2004 global production of 1,244,637 tonnes of farmed Atlantic salmon, we can estimate that in 2004 the GFASI contributed 7,032,199,050 kg, or about 7,032,200 tonnes, of CO_2 to the atmosphere. This contribution can be translated into social costs (based on the US$ 85/tonne of CO_2 (2000$) value used by Stern (2006). If the Peruvian anchovy fishery was required to internalize their share of these costs, that fishery as currently operated might no longer be profitable.

Table 17. Possible implications of global warming on the quantity and quality of fish available for consumption by Peruvians

Implication of warmer global climate	Implication for QUANTITY of fish available for Peruvian consumption	Implication for QUALITY of fish available for Peruvian consumption
Increased frequency, duration, or magnitude of ENSO events	Reduced quantity through reduction in anchovy population and related reduction in population of desired food fish that feed on anchovy	Decreased availability of fish at higher trophic levels leading to possible reduction in availability of micronutrients associated with these fish; possible reduction in total protein available from fish
Increased regional drought or precipitation	Uncertain	Uncertain
Coastal flooding consequent to sea level rise	Indirect reduction in availability of desired food fish through disruption of fish processing capacity in coastal areas and decreased export earnings and household income; indirect reduction in availability of desired food fish through destruction of fishing capacity	Uncertain; decrease in quality may result from different mix of available fish species
Changes in habitat parameters for caught fish (e.g., warmer average water temperature, reduced oxygenation of water)	Reduction in anchovies; reduction in desired food fish that feed primarily on anchovies	Uncertain; decrease in quality may result from different mix of available fish species

Implication of warmer global climate	Implication for QUANTITY of fish available for Peruvian consumption	Implication for QUALITY of fish available for Peruvian consumption
Changes in habitat parameters for primary producers and/or top predators with which caught fish are related ecologically	As immediately above	As immediately above

Monetary flows are implicated in all of these predicted impacts, complicating the situation. Increased household or national income from other enterprises could offset losses from fish and fish product income; quantity and quality of fish available for domestic consumption could be maintained, at least over some time scales, by the purchase of imported fish. Management of fish stocks via fishing regulation and enforcement may mitigate the effects on availability of fish that are related to regional/local ecological change driven by global-scale processes. And, the adaptation costs of internalizing the Peruvian share of the social costs of carbon associated with the reduction fisheries, should the demand for that internalization process occur, could spark changes in other Peruvian fisheries, thus also influencing the quantity and/or quality of fish available for consumption domestically.

In addition, other policy-related factors are likely operative and relevant to regional/local ecological change driven by both global *and* regional/local scale processes. For example, unofficial sources indicate that roughly 10% of all Peruvian anchovy production is packaged for human consumption and sold either domestically or internationally, but that Peru plans to increase this proportion to 20% or 30% in the future. This would not affect the total amount of fish caught and thus the regional/local ecosystem dynamics, but it could affect the quantity and the quality of fish ultimately available for Peruvian consumption.

Some of these relationships may be explored, or at very least hypotheses may be generated and tested, using existing aggregate data. For example, on average real income has risen in Peru from 1975-2004 (World Bank, 2006), and as a result, the affordability of foodstuffs in the aggregate and the affordability of fish and fish products have increased. However, as Figure 10. shows, in Peru the amount of fish consumed per capita has fluctuated yearly but shown no upward or downward trend in that same period (FAO, 2004).

Like many other nations, Peru exports food types that it also imports; for example, in 2001 Peru exported 317,000 tonnes of fish and fish products for direct human consumption, and imported 43,000 tonnes of fish and fish products for direct human consumption (FAO, 2003). Peru thus depends on food production capacity in ecosystems all over the world. Many of these ecosystems will be outside of the GFASI's direct influence because they provide no input material (like anchovies) to the industry. However, so long as the GFASI is a buyer of materials such as feed pellets that contain non-fish ingredients like soy and corn, it participates in the market for these commodities and appropriates some of the food production capacity used to generate them. It also affects pan-oceanic dynamics via its contribution to climate change, and via its demand for fish from fisheries in several locations on the planet. Because of this, the answer to the question that was originally rejected as too broad—namely, the question of whether the amount of bioproductive capacity for food (or, more specifically, high-quality protein food) production on Earth currently appropriated by the GFASI is ethically and strategically defensible given world food needs—may still have relevance for the population health of Peruvians. This is because both Peru and the GFASI are linked through their common participation in the larger global food market. Investigation of the nature of these links, however, is beyond the scope of this study.

5.4.5. Population health impacts related to the GFASI's ecological footprint

Population health impacts related directly to the GFASI's contribution to global ecological overshoot are those impacts that stem from the loss of the ecosystem goods and services provided by global ecosystem types that support the GFASI's annual production. Because EFA deals with renewable resources and the ecological stock required to assimilate wastes from non-renewable energy inputs such as oil, ecological overshoot can also be conceived in terms of the amount of time it would take the biosphere to renew the resources consumed in a single year. Given current overshoot of approximately 20%, Earth requires about one year and 2-3 months to renew the resources consumed in a year, given the current world population and prevailing technology. However, for many reasons the situation is more complicated from a prediction or modeling standpoint. These reasons include:

i) Uncertainties in the rate of population growth;

ii) Uncertainties in the rate of change of technology, and in the spread of new technologies with lesser or greater impact;

iii) Uncertainties in the rate of consumption;

iv) Non-linear relationships between loss of ecological capital and the annual production of ecosystem goods and services that support human population health—e.g., the decrease in annual "interest" may not be linearly proportional to the reduction in capital;

v) Discontinuities in relationships between loss of ecological capital and the annual production of ecosystem goods and services that support human population health;

vi) The impact of geopolitical change and stress, including wars, political instability, and mass human migration;

vii) Capacity of human technology and trade to mitigate impacts of destruction of natural capital (related to the rate of change of technology and its spread, as well as to the geopolitical balance of power); and

vi) Interactive relationships of the above over time.

Thus, there are two broad areas of uncertainty about how humanity's ecological overshoot (i.e., using ecological capital and not just ecological interest) will result in ecological changes that impact population health. These areas of uncertainty have to do with (1) details of humanity's demand for ecosystem goods and services over time; and (2) knowledge of how complex ecosystems, including the ecosphere as a whole, function under various types and durations of stress.

These two domains of uncertainty combine with lack of data and knowledge of the relationship between indicators of decline in Earth's ecosystems and impacts on human population health. Our current study's concern both with the ecological impacts of the GFASI that occur through global scale phenomena such as global warming (to which the GFASI contributes via its consumption of carbon-based fuels), and with regional/local scale ecological impacts in which the GFASI is believed to be implicated, such as those in the HCUE that we propose are spurred in part by increased fishing pressure in the Peruvian anchovy industry, is focused on specific impacts: reduction in the quantity and/or quality of fish available for consumption by Peruvians. These outcomes of ecological change (which become the proximate exposures for the nutrition-related disorders in which we are interested) are neither the only outcomes nor necessarily the most important or the most easily investigated outcomes associated with the ecological changes that the GFASI causes; they are outcomes on which we have chosen to focus in order to bring to light the kinds of issues that need to be resolved when attempting to research questions having to do with the human health impacts of globalization. With respect to population health in Peru, many of the variables likely involved in this process were discussed in sections 5.3. through 5.3.2., but much further work on the relationships between these variables remains to be conducted.

5.5. The accounting framework

In section 2.5.1. through 2.5.8. of Chapter 2, the concept was introduced of an accounting framework for guiding the assessment of the ecologically-mediated population health impacts of specific global industries. In that part of this study, we discussed the purpose of such a framework and considered some of the challenges in translating a useful concept into a practical investigative tool. We also proposed four key questions, the answers to which would essentially define the accounting framework. Each of these questions is considered in detail below. For illustrative purposes, reference is made frequently to the global farmed Atlantic salmon industry, although the accounting framework is conceived as a tool which can be applied to any global-scale industry, and which also can be adaptable to smaller enterprises with more limited geographic reach.

The impossibility of including an analysis of all dimensions of ecological and related population health impacts in the accounting framework needs to be tempered. As with EF assessments, the accounting framework cannot be expected to facilitate an exhaustive accounting of every ripple of impact at all temporal and spatial scales, but rather needs to be seen as a "big picture" analysis that can put competing human uses of the biosphere into a context for comparison (Wackernagel et al, 1999).

(1) By what method(s) will the identity of an industry's known or potential ecological impacts be determined, and according to what criteria will those impacts be included in the accounting framework?

This question addresses the key issue of scoping: which of the ecologically relevant activities associated with an industry's total web of economic relationships should be attributed to that industry (versus that of another industry or human enterprise)? This question also asks how all identified ecological impacts will be measured. The quality and relevance of that measurement will influence the answers about ecologically-mediated population health impacts, which are the focus of the next question (Question 2).

At a minimum, the extent of an entire industry's impacts should be no less than the extent of the impacts of all of the firms in that industry. In other words, one cannot, for example, speak of the ecological impact of the entire GFASI without access to accurate data from all the firms in the industry, since different firms track their inputs ultimately to different marine and terrestrial ecosystems on Earth. Production levels also vary among firms. In the material that follows, all references to the "industry" should be understood as references to the sum of all the impacts of the individual firms in the industry, each of which may be assessed using the accounting framework

Our consideration of the GFASI showed that the ecological impacts from a global industry may all be realized through changes at the regional/local scale, but driven either by processes operative at that scale or by processes operating at the global scale. Thus, for example, each industry that burns carbon-based fuels contributes to global climate warming, which then affects particular ecosystems on Earth. Each industry also has impacts directly at the regional/local level. For example, the demand of the GFASI for fishmeal and fish oil contributes to pressures on particular marine ecosystems in addition to any impacts operating through changes to global scale processes.

Since ecological change processes cannot be neatly divided into a small and finite number of scales (e.g., "global," and "regional/local") because these processes are interrelated, one possible provisional solution is to treat the aggregate ecological footprint (EF) for the industry as the main indicator of impact at the global scale, and to disaggregate the EF for identification of specific ecological impacts at all other scales. Anielski (2001) provides a series of categories or sub-accounts into which aggregate natural capital can be disaggregated. These include the EF at both the industry and individual consuming household levels, itemized renewable and non-renewable natural resources (flows) or provisioning ecosystem types (stocks), such as forests (for timber and non-timber uses) and oil, and indicators of environmental quality such as levels of toxic waste pollution and water quality and flow. Ideally, each firm in a global industry would provide data for evaluating its influence on each component of this full suite of natural capital sub-accounts. Where research resources are lacking, case studies such as that of the GFASI in this study can point to priority areas of natural capital accounting for a particular industry. For example, impacts on fisheries and marine ecosystems are likely to be the most important specific ecological impacts of the GFASI; more care should be devoted to evaluating these impacts prior to evaluating the impacts of the GFASI on mineral resources (even though some of the latter are used by the GFASI, and the impact is not negligible).

As shown in Table 2. in section 1.8., ecosystems provide a multiplicity of diverse goods and services that make human life possible. Requiring industries to account for the impact of their operations on all of these ecosystem goods and services in theory would be more valuable than an accounting of impacts on a more limited number of natural resource accounts (such as those mentioned above), but knowledge of the relationship between many of the ecosystem goods and services described in Table 2. and human health is not developed to the point where illuminative epidemiological conclusions can be drawn. Some useful data are available, however, on the quantity and quality of some natural resource stocks such as forests and surface water.

It is beyond the scope of this study to suggest how important social and economic impacts of industries, potentially relevant to population health and, in many instances, likely of more immediate concern to policy-makers than ecological integrity, might be integrated into a *comprehensive* accounting framework for industrial application. The Genuine Wealth model of Anielski (2001, 2004) outlines a process for assessing the current status of, and trends in, five types of capital in a political jurisdiction, business or organization: human, social, natural, manufactured, and financial. The Canadian Index of Well-Being, incorporates multiple indicators of social health that largely overlap with these five capitals (Canadian Index of Well-Being, 2007). All of the five capitals affect human health, but our focus in this section remains mainly on the impacts on human health stemming from contributions of industry to ecological change: global ecological overshoot and global warming as global-scale impacts, and changes in the quantity or quality of natural capital (defined as the stocks and flows of ecosystem resources), including EI, at the regional/local scale.

Firms in industries are required to account for monetary costs of operations. Data are therefore available for the full range of inputs used by each firm. These inputs all have geographic origins, locations of actual use, and further geographic features related to their disposal, recycling, reuse, or reintegration into the natural environment. A variety of Product Life-Cycle Analysis (PCLA) techniques are available for tracking impacts through time and space. For example, the fish oil component of farmed Atlantic salmon feed material may be traced to its origin in particular fish populations living in particular ecosystems; the later "use" of the fish oil, which consists of a farmed Atlantic salmon consuming feed pellets that included the fish oil, may be traced to particular locations such as a grow-out operation on the coast of Chile; and the penultimate destiny of that fish oil could, in theory, be traced to the location of the actual consumption of the farmed Atlantic salmon in which the fish oil was embodied—for example, a restaurant in New

York City. An itemized, life-cycle accounting of the multi-scale ecological impacts of every single item used by a firm (or, for that matter, used by every company which is financially solvent because of the patronage of the firm) implies an impossible research task for either the firm or an outside investigative body. It may be possible to randomly or selectively audit certain single constituents in order to determine potential new pathways of impact (for example, there is little information on the environmental and human health implications of thousands of industrial chemicals in circulation), but the value of the accounting framework will lie in its ability to focus research on the most significant areas of ecological impact of an industry. The guideline questions provided in Table 22. are intended to assist with this focusing process.

In sum, the methods that will be used to determine the extent of an industry's known or potential ecological impacts are as shown in Table 18.

Table 18. Methods for determining extent of ecological impacts

Scoping and types of ecological impact	**Method(s) for identifying impact**	**Criteria for inclusion of ecological impact(s) in the accounting framework**
General features of industry: ecological, economic, sociopolitical	Case study	None; requisite for all uses of the accounting framework
Impacts influenced by global scale drivers (e.g., global ecological overshoot, global warming)	Primarily Ecological Footprint Analysis (EFA); special attention to carbon emission assessment and to impacts occurring at distance from primary sources (e.g., island nations, coastal areas of other continents, other vulnerable regions)	None; requisite for all uses of the accounting framework

Scoping and types of ecological impact	Method(s) for identifying impact	Criteria for inclusion of ecological impact(s) in the accounting framework
Impacts on specific ecosystems stemming from specific inputs and outputs of industry (includes impacts that affect the quantity or quality of specific ecosystem goods or services, and EI)	Disaggregation of EF; PLCA; possible use of DPSEEA or Pressure-State-Response (PSR) frameworks; utilization of existing science-based knowledge of relationships between exposure to environmental toxins and health outcomes. In the future, Index of Biotic Integrity (IBI: Karr, 1991) may be useful in this application; use of local and regional level data on ecosystem health in identified locations of impacts	Second-generation impacts excluded, according to most PLCA practice; Choice of impacts for inclusion based on major themes of industry (e.g., the ecosystems supporting the reduction fisheries which provide fishmeal and fish oil for the GFASI)

(2) How will the subsequent determination of known or potential population health impacts from these ecological impacts in (1) be made, and on what basis for inclusion in the accounting framework?

As noted earlier, great uncertainty exists about the relationships between the stock and flow features of particular ecosystem goods and services, and human population health. Not only so, but the relationship between ecosystem integrity, as defined by an ecosystem's ability to withstand perturbations, and human health is even more uncertain. This is because critical system flip or collapse points for ecosystems, which may result in profound impacts on human health, are largely unknown, and also because the human impress on Earth's ecosystems has contributed to situations of unprecedented and unknown risk. Dealing with various types of uncertainty in the accounting framework is discussed under Question 3 below.

Recognizing much uncertainty, our case study of the GFASI in this study, and to a greater extent prior work, has been able to affirm nonetheless several basic understandings about the relationship between ecological conditions (whether of the status of particular ecosystem goods and services or of EI itself) and human health. These include:

1. Simple lack of discrete natural resources or ecosystem goods such as timber, arable land (quality soil), and fresh water is a very important contributing cause of disease and death in many places in the world (WHO, 2005; United Nations, 2001).
2. The human health implications of the loss of regional/local ecosystem goods and services and/or EI depend largely on the degree to which the affected population obtains its necessities from the immediate locale or region, and there may be delays between ecological impacts and human health effects. Monetary wealth income, as a marker for the ability to purchase imported goods or to relocate successfully if local ecological conditions become inhospitable, is ostensibly an important modifier of this relationship.
3. International trade obscures the relationship between EI and human health at smaller (e.g., country-level) scales (Sieswerda et al, 2001; Huynens et al, 2004).
4. Ecosystem flip, re-equilibration, or collapse points are often unknown and unpredictable (McMichael, 1993).
5. Human modification or simplification of ecosystems can substantially reduce the ability of these systems to buffer against high-energy, single-event stressors such as tsunamis, floods, or fires. Typically, the human health consequences of such events are magnified as a result; the loss of life from tsunamis caused by the Sumatra-Andaman earthquake of 2004, which likely would have been less if coastal mangrove ecosystems in hard-hit areas of Thailand had not been previously destroyed for shrimp farming and other industries, is a prime example. The relationship between human modification of the landscape and changes in risk from natural stressors, for humans living in modified areas, is, however, often complex; ecological impacts from industry are not the only forces affecting vulnerability.

6. The relationship between natural capital and/or ecological integrity needs to be understood within a framework of socio-economic, political, and cultural forces that determine the consequent impacts on affected populations (Huynens et al, 2006).
7. Much research has been conducted on the relationship between exposure to individual environmental contaminants (such as airborne pollutants, heavy metals, and persistent organic pollutants) and human health; while research into these connections has long been the concern of environmental epidemiology and toxicology, the issues remain relevant whenever human health consequences mediated by industrial activities are considered.

Each of these understandings is useful in helping answer Question 2.

By dealing with the related implications for human population health, Table 19. adds a second layer of complexity to the task of identifying ecological impacts and applying consistent criteria for the inclusion of those impacts in the accounting framework. It should be kept in mind that the division of ecological impacts into those which stem from global scale drivers (such as climate change), those described by changes in the quantity or quality of ecosystem goods and services, and those described by changes to EI (which may reduce the resilience of the system to unexpected stressors) is not based on the clear observation of these divisions in the natural world. As noted earlier in the sections on the GFASI, global scale changes such as global warming are still "felt" or realized through the changes that a warmer (global) climate causes to the regional/local scale ecosystems that actually provide the goods and services utilized by human beings. Further, the categories of impact are interrelated. Our distinction between quantity and quality of ecosystem goods should also be kept open to critique and refinement, since certain kinds of pollution can reduce the amount of a resource (such as freshwater) that is practically available even though the gross quantity may remain unchanged. Thus, the division of impact types noted in Table 18. and Table 19. are intended to facilitate the process of looking for and identifying ecological and ecologically-mediated population health impacts, respectively, and also to suggest that multi-scale interventions may be most effective at improving population health outcomes or reducing risk factors.

Table 19. Methods for determining relationship between ecological impacts and population health impacts

Scoping and types of ecologically-mediated population health impacts	Method(s) for identifying population health impacts and clarifying relationships between those impacts and their putative ecological causes	Criteria for inclusion of population health impact(s) in the accounting framework
Population health impacts attributable to global ecological overshoot to which the industry contributes (i.e., impacts related to non-sustainability) or global warming	EFA coupled with information from climate change modeling, economic (production/consumption) trend analysis, technological development and uptake information, and demographics—ideally, transdisciplinary investigations. As with methods noted in Table 19., special attention should be paid to impacts located distant from primary sources of exposure generation, since issues of distributive justice (equity) and autonomy are especially relevant	All impacts related to global scale drivers of ecological change to which the industry contributes should be included, but with responsibility for those impacts carefully apportioned to the industry according to the industry's contribution to net total GHG emissions. Positive population health impacts from ecological change must be included as well, since this will permit analysis of the distributive justice of the impacts
Population health impacts attributable to changes in specific ecosystems that result in the loss or degradation in the quality of specific ecosystem goods or services (e.g., increased infections from vector-borne disease resulting from loss of natural biological vector control or displacement of vector habitat)	Traditional methods of environmental epidemiology can resolve some questions, especially where individual level exposures can be measured accurately and sources of exposure can be fairly attributed to a particular industry. Absent these kinds of data, the DPSEEA or PSR model, with a deliberate focus on clarifying the nature of drivers (D) and pressures (P) stemming from specific industries, will be useful	Impacts stemming from the operation of all physical plant and labour activities under the ownership or managerial control of the industry, or which is/are substantially financially dependent on the industry for solvency (wherever located)

Scoping and types of ecologically-mediated population health impacts	**Method(s) for identifying population health impacts and clarifying relationships between those impacts and their putative ecological causes**	**Criteria for inclusion of population health impact(s) in the accounting framework**
Population health impacts related to the loss of EI and increased risk from otherwise natural, high-energy (e.g., tsunamis) or periodic (e.g., ENSO) stressors	Information based on the experience of historical events (e.g., tsunamis, hurricanes, fires) can provide estimates of the increase in risk to human beings from various levels of loss of the buffering function of intact ecosystems. Ongoing work to link CO_2 emissions, global warming, the frequency and intensity of extreme weather events, variation in the vulnerability of subpopulations to such events, and human health impacts, may yield useful information in the future	Inclusion based on industry responsibility for initiating loss of EI through direct degradation of the ecosystem or through authorized degradation via physical plant or labour activities as framed immediately above. Improved understanding of the relationship between CO_2 emissions and eco-health events of interest (see column to left) may enable assignment of a share of the responsibility to a particular industry, justifying inclusion in the accounting framework

(3) How will uncertainty be addressed in (1) and (2) above, relating to existing knowledge of ecological and population health states and trends, causal relationships, and the validity and power of the methods of analysis?

This question asks how several types of uncertainty, which are relevant to the construction of a functional accounting framework in our area of interest, will be addressed: uncertainty about basic features of ecosystem constituents and the dynamic relationships between those constituents (including the points at which dramatic system flips can occur); uncertainty about the time scales for ecosystem recovery or restoration if provisioning functions have been compromised or lost; uncertainty about which population health indicators are most sensitive to changes in the provisioning of ecosystem goods and services or EI; uncertainty about the nature of the causal pathways (or webs) running from specific types of ecological impacts to specific population health outcomes at multiple spatial and temporal scales; and (partly owing to the unprecedented nature of the exposures) uncertainty about the power and validity of the methods used in research in this field, including methods used to estimate ecological conditions and related human health impacts relevant only to future generations.

The consistent, and, for some ecosystem types, accelerating degradation of Earth's life support systems by human activity (WWI, 2006)—including the process of climate change—forces re-thinking of how we have dealt historically, and how we deal currently, with uncertainty in the domains noted immediately above. Creative research in the fields of ecology, public health, climatology and earth sciences, and other disciplines can increase knowledge about the workings of natural systems, and improvements in study design, statistical methods, and mathematical modeling techniques can lead to more accurate estimations of the magnitude of some types of uncertainty associated with hypothesis testing or modeling. However, the complexity of the systems and questions involved suggests that any reductions in uncertainty will be piecemeal, and that new areas of uncertainty will continually arise. Thus, given the critical state of Earth's major ecosystems, the policy position of proceeding along business-as-usual (BAU) lines in the face of uncertainty may be nothing less than catastrophic for human health in the long-term. The conservative nature of the scientific method in terms of claims about relationships in the phenomenal world, the legal bent of presumptive innocence until guilt is proven (beyond a reasonable doubt), the responsibility for the burden of proof of guilt, and the discounting of harms to future generations all mitigate against placing limits on ecologically aggressive modes both of making money and of concentrating it among those individuals or populations that are already beyond the point where increases in monetary wealth can bring other than very marginal gains in health status.

An important additional type of uncertainty is the uncertainty of attribution. Industries, individuals, governments, and other entities make incremental contributions to major ecological change at the global scale. Can the precise contributions of each of these entities be known? Further, if these contributions can be known, can responsibility be partitioned for any downstream human health impacts? Another section of the larger project of which this study is part will deal more directly with this question. Table 20. below reflects a proposal for approaching and obtaining provisional resolution of the types of uncertainty likely to arise in the accounting process.

Table 20. Dealing with uncertainty in the accounting framework

Scale of ecological driver of population health impact	Relevant types of uncertainty	Approach to/resolution of uncertainty in accounting framework
Global (e.g., global ecological overshoot, global warming)	All noted above; increasingly less uncertainty about the phenomenon of global warming and of fundamental measures of unsustainable demands on Earth's bioproductive capacity	Ensure clarity of assumptions and calculations used in EF analysis, and justify all novel interpretations of results; use of data from credible sources
Regional/local (related to loss of, or change of quality in, ecosystem goods and/or services)	All noted above; may be greater certainty about impacts on specific ecosystem goods and services because historical data are available and causal pathways are less complicated	Establish appropriate monitoring (data collection) programs to ensure possibility of accurate trend analysis; reliance on best evidence available for decision-making, not automatic default to BAU operation where lack of full certainty is present, and where potential negative ecologically-mediated health impacts would be realized by involuntary non-beneficiaries of the BAU operation
Regional/local (related to reduced ability of regional/local ecosystems to withstand stressors because of loss of EI)	All noted above; indicators of EI are still being developed and refined; improving certainty about risk based on historical data about events where human alteration of ecosystem buffering functions has increased population health impact of event	Use of best EI indicators available; use of all relevant historical data on amplifications of human health impact from stressors as a result of diminished EI; less conservative criteria for establishing responsibility when exposed population(s) is(are) involuntarily exposed

(4) How will the characteristic features—in time, in space, and in strength of association with putative ecological cause(s)—of the population health impacts be interpreted within the accounting framework so that policy-makers might better understand (1) the ecologically-mediated costs to human health and well-being from industrial business-as-usual (BAU) modalities over multiple time scales; and (2) the changes to those industrial BAU modalities that would be required to reduce the ecologically-mediated costs to human health and well-being over these same time scales?

This two-part question aims at bringing the theory of the accounting framework into a key service of epidemiology in public life: providing knowledge for the development of effective policies to prevent disease and death and improve equity in the distribution of the determinants of health and well-being. It is a difficult question to answer; our task is to clarify what the question is asking and to suggest the kinds of research needed to answer it.

The question asks how the strength of the relationships between population health impacts and their ecological antecedents, their timing, and their location (i.e., the identity of the particular populations in which they are realized)—will be interpreted for policy-makers. It also asks how this information will help policy-makers anticipate the effects of different courses of action, taken with respect to industrial activity, on population health. These courses of action could entail: permitting, qualifying, or prohibiting the expansion of an industrial activity; screening proposed activities; consuming products in the marketplace; increasing or decreasing trade with an international trading partner; and defining access to, and responsibility for impacts on, the flows of ecosystem goods and services and the foundational ecological stocks that provide these goods and services.

In terms of global industries such as the GFASI, BAU modalities relevant to ecologically-mediated population health impacts can be defined as those practices that perpetuate the *status quo*. This means practices that either maintain current conditions into the future (such as the current distribution of energy and material resources among nations) or that extend historical trends (such as growing anthropogenic contributions to atmospheric CO_2) into the future. Important BAU practices apparent or believed likely in the context of this present study include the perpetuation of national trade imbalances in biocapacity even when basic domestic needs remain unmet, the conduct of energetically inefficient trade, and corporate accounting that fails to incorporate the human health costs of ecological externalities. All of these practices may have negative ecological impacts of the types noted in Tables 18., 19., and 20. above: impacts that contribute to ecological overshoot, impacts that change the capacity of specific regional/local scale ecosystems to provide the full range, quantity and quality of their goods and services, and that increase human health risks by diminishing ecological integrity and increasing vulnerability to natural (or other human caused) stressors.

BAU modalities also have to do with ways of treating uncertainty of the various types noted above, including assigning the burden of proof in situations where scientific resolution is required by a government, court of law, or other body. A regulatory approach that assumes the "presumptive innocence of chemicals" (Wildsmith, 1986) and places the burden of proof of harm on the aggrieved party (once those chemicals are already circulating in the environment and economy), is one such modality.

Table 21. lists several BAU modalities or practices related to the varieties of ecological impacts presented in Tables 18., 19., and 20. Questions which need to be answered by, or for, policy-makers with respect to temporal, spatial, and scientific (e.g., relative certainty) features of these impacts are also noted. Relevant public health ethics are also interpreted in this context.

Table 21. Business-as-usual practices related to ecology and human health

Business as usual (BAU) practice	Issues relevant to the temporal features of the ecologically-mediated population health impacts	Issues relevant to the spatial features of the ecologically-mediated population health impacts	Issues relevant to the scientific features of the ecologically-mediated population health impacts	Interpretation of relevant public health ethics of autonomy and equity
Perpetuation of national trade imbalances in biocapacity (i.e., exports of biocapacity exceed imports plus domestic stock) even when basic domestic needs for goods and services derived from bioproductive areas remain unmet	1. Discount rate used for valuation of health impacts on future generations or on the current population at future times 2. State of knowledge about the biocapacity in future years (e.g., if or when major tipping points are anticipated with current or expected production trends) 3. Trends in other buffering or modifying variables (e.g., technology, government policies)	1. Distribution of impacts among nations and among sub-populations in those nations	1. Increasing uncertainty of the types and magnitudes of impacts with the passage of time 2. Meaningful measurement of biocapacity, including development and use of valid indicators	Autonomy: Populations or sub-populations bearing ecologically-mediated health risks or impacts associated with trade imbalances in biocapacity may bear these risks or harmful impacts involuntarily Equity: Populations or sub-populations bearing ecologically-mediated health risks or impacts associated with trade imbalances in biocapacity may bear these risks or harmful impacts in disproportion to the health or wealth benefits realized by the populations or sub-populations accruing the benefits from the existing conditions of trade imbalance in biocapacity

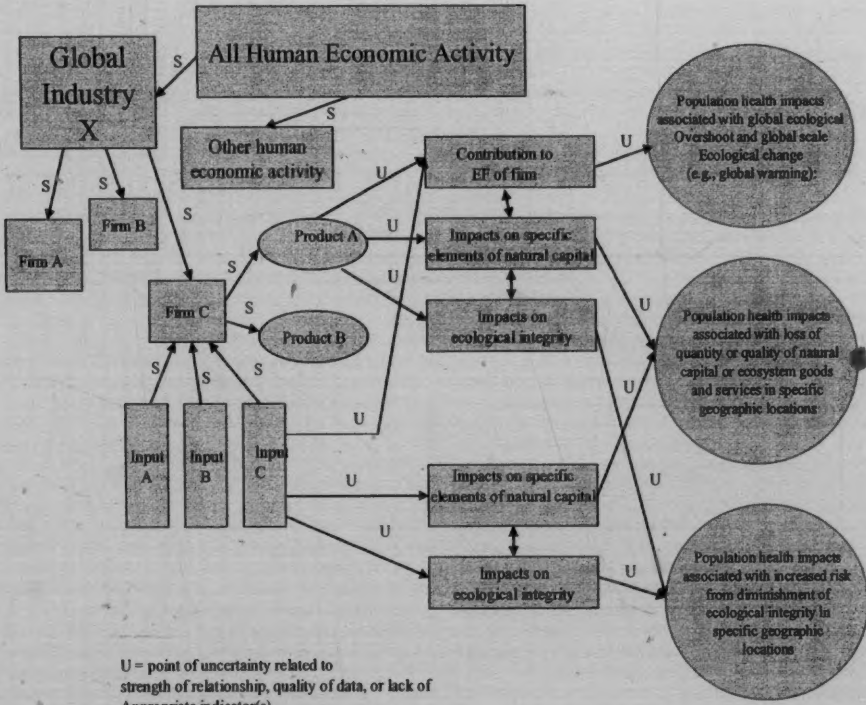
Business as usual (BAU) practice	**Issues relevant to the temporal features of the ecologically-mediated population health impacts**	**Issues relevant to the spatial features of the ecologically-mediated population health impacts**	**Issues relevant to the scientific features of the ecologically-mediated population health impacts**	**Interpretation of relevant public health ethics of autonomy and equity**
Energetically inefficient trade (e.g., export and import of identical products, such as may occur in international commodities markets for major grain crops)	1. Discount rate used for valuation of health impacts on future generations or on the current population at future times 2. State of knowledge of the current health of the ecosystems supplying the traded goods or services, and knowledge of trends in changes in those ecosystems	2. Distribution of impacts among nations and among sub-populations in those nations	1. Data on energy consumption associated with current trade arrangements, including sources of energy and the ecological impacts associated with the derivation and consumption of energy from those sources	Autonomy: Abstraction of production from national/regional consumption needs, where these are not being met adequately, places vulnerable sub-populations at the dictates of the international buyers and sellers; risks and harmful impacts may be borne involuntarily Equity: Affected populations may bear risks or harmful impacts in disproportion to the benefits realized by those benefiting materially (in terms of the consumption of the goods themselves), monetarily, or in other ways from the energetically inefficient trade arrangements
Corporate accounting that fails to incorporate the human health costs of ecological externalities	1. Discount rate used for valuation of health impacts on future generations or on the current population at future times 2. Locations and types of ecological externalities and prior (baseline) states of affected ecosystem(s)	Distribution of impacts among nations and among sub-populations in those nations	1. Certainty with which specific ecological impacts can be attributed to specific industries or firms within those industries 2. Making attributions in cases of cumulative impacts	Autonomy: health risks and harmful impacts borne by populations as a result of industrial activity that impacts ecological conditions, but which is not accounted for, represents involuntary exposure Equity: Costs are not paid by the party(s) responsible for incurring those costs

Key questions remain to be answered about the compromised autonomy of those populations affected by ecologically-mediated health risks and impacts, the equity of benefits and risks or harms among affected populations, the locations and timing of impacts, and the scientific concerns associated with determining ecologically-mediated population health impacts caused by global industries.

5.6. Conclusions from explorations of Questions 1-4.

The development of precise, practical guidelines for employing the accounting framework requires taking the broad conceptual contours developed above and finding consistent ways to embody them in the practice of assessing the impacts of specific global industries. Figure 18. shows in schematic form the basic information needs and flow of analysis in the accounting framework, including points at which scoping decisions must be made and points at which uncertainty must be addressed.

Figure 16. Schematic of accounting framework


Global Industry X
All Human Economic Activity
Other human economic activity
Firm A
Firm B
Firm C
Product A
Product B
Input A
Input B
Input C
Contribution to EF of firm
Impacts on specific elements of natural capital
Impacts on ecological integrity
Impacts on specific elements of natural capital
Impacts on ecological integrity
Population health impacts associated with global ecological Overshoot and global scale Ecological change (e.g., global warming):
Population health impacts associated with loss of quantity or quality of natural capital or ecosystem goods and services in specific geographic locations
Population health impacts associated with increased risk from diminishment of ecological integrity in specific geographic locations
S
U

U = point of uncertainty related to
strength of relationship, quality of data, or lack of
Appropriate indicator(s)

S = point where inclusion/exclusion decision
(i.e., a scoping decision) needs to be made

Figure 16. shows that accounting for a global industry's ecologically-mediated population health impacts requires complementary investigations in at least three broad domains. The first is related to delineation of the actors in the industry itself (the firms and all of their relevant outputs and inputs). The second type of investigation consists of establishing connections between those outputs and inputs for which the firms in the industry are responsible, and the ecological impacts of those outputs and inputs. The third type of investigation is that which can be described as eco-epidemiological: describing the connections between ecological impacts and human health outcomes. Epidemiology also is properly concerned with the ethical issues (such as distributive justice) related to the identified human health impacts. This constitutes the fourth domain of investigation, not represented in the schematic.

Determining the lines between one global industry and another is one of the scoping issues, as noted in Figure 16. Different issues will arise with each industry, so no hard rules on boundaries can be established. In our case study, for example, we considered the GFASI to be a distinct industry, but there are also good arguments for treating the entire global farmed salmon industry (i.e., all production of farmed salmon, including both the Atlantic and Pacific species) as a single entity. Thus, it is important to be clear about the frame that is placed around the particular industry for which the accounting is to be conducted, and for the choice of those limits to be justified.

The full roster of firms in a specific industry also must be identified. Because firms enter and exit industries as well as combine within industries to form larger firms, accurate allocation of responsibility for industry impacts must take stock of these ongoing changes. Such monitoring of sources of impacts is consistent with regular assessments of the genuine wealth of society, and allows analysis of trends as well as possibilities for hypothesis testing.

In addition to determining all of the firms in an industry, an assessment using the accounting framework requires scoping of both the products and the important inputs to the firms in the industry. The areas where this scoping is needed are identified in Figure

16. The scoping of products is related to the narrowness of the definition of the industry itself; in both cases all inclusion/exclusion decisions must be justified.

Determining ecological impacts from the industry's products and major inputs requires the use of the tools and methods described in Table 18. Uncertainty of the types noted under Question 3. attends these processes. Also, while the production of products (outputs) and inputs to the industry will contribute to the EF of the industry and to the industry's overall impact on global-scale processes such as global warming, impacts on elements of natural capital may be diverse in kind, timing, and specific location. Thus, there are impacts to which products and inputs contribute together, and there are impacts to which they contribute independently.

The two-headed arrows between the boxes describing the different types of ecological impacts show that while the forces contributing to these impacts may or may not be independent, the impacts themselves are likely not independent of one another. There is practically always some kind of interaction; change in the quantity or quality of some element of natural capital, for example, will almost certainly have an influence on ecological integrity at some scale. While this interdependence complicates attempts to identify discrete impacts from discrete causes, it also suggests how interventions might have multiple positive effects on ecologically-mediated health outcomes.

Figure 16. indicates that various types of uncertainty also attend the process of determining how and to what extent population health impacts are determined by the different types of ecological impacts. The tightly dotted lines that circumscribe the three different major types of population health impacts are intended to show that the boundaries between these health impacts are conceptual and tentative. These impacts may be relatively singular in cause, and uninfluenced by any changes in the regional/local ecosystems in which this specific mortality increase is transpiring. Population health impacts related to the loss of a specific ecosystem good or service in a specific regional/local context, by contrast, may stem from regional/local scale drivers of change (such as overfishing in a particular marine ecosystem), from global scale drivers of change (such as global warming, which may create extensive changes in the primary productivity of all marine ecosystems), or from the combined influence of drivers at both scales. Again, the value of the accounting framework rests in its capacity to help organize and focus the search for relevant relationships in the midst of uncertainty in a consistent manner, and to establish the most important possible, probable, and demonstrable ecologically-mediated health impacts for a given industry—not in precisely describing and attributing all of these impacts.

The case study explored in the previous sections of this report revealed many of the complexities and challenges in attempting to answer the epidemiological question of whether the GFASI is affecting the health of Peruvians. It showed the need for a large number of questions, about how the ecological, economic, and socio-political worlds actually work, to be answered prior to the testing of focused hypotheses about specific exposures and specific health outcomes. Not only was more complete information required about the causal systems, but data and meaningful statistics indicating trends and discontinuities over time between related elements of that system were also needed. Further, the system in which more specific epidemiological questions might be asked is not closed; the size and impact of the GFASI is influenced strongly by what is taking place in other industries, including those that supply key inputs to the GFASI's production. Recommendations for further research and improved data coverage are made in Chapter 7. Finally, it is important that the proposed causal web shown in Figure 13. only dealt with a small set of possible population health outcomes on one population in one geographical location in which the GFASI has influence, and thus did not represent the MEME context of the situation. Identifying all of the possible and known ecologically-mediated population health impacts of the GFASI, and then answering the multiple relevant questions associated with each of these impacts, would be an impossibly large task. However, limits might be placed on the extent and depth of knowledge required to inform policy decisions, and overarching goals (such as the attainment of bioregional sustainability) could be useful. Given the global reach of many modern industries, the lack of a sufficiently precautionary approach to their evaluation—i.e., one that identifies and quantifies/qualifies possible and probable ecologically-mediated population health impacts prior to the initiation of, during, and at proposed expansion points in that industry's operation, and which evaluates these impacts through a transparent ethics of distributive justice—seems likely to contribute to the perpetuation of the destruction of ecological life-support systems on a global scale.

5.7 Scenario development as a complement to the accounting framework

The accounting framework described in the previous sections is intended to guide the evaluation of a global industry at a single point in time. This is problematic for interpretation because industrial impacts on ecology grow, diminish, and change as the industry grows (from a zero impact point at some time in history) and as other industries also grow and change. In terms of determining an industry's impacts on ecologically-mediated population health, then, it is most useful to track changes over time. Since industries consist of firms that produce saleable goods and services for which there are dynamic supply and demand functions, future projection of key trends may be useful, especially for young industries for which a limited time series of historical data is available but for which indications of future growth are strong. The GFASI is one such industry.

In investigations that require systems thinking and/or mathematical models and that deal with consequences which are global in scope and potentially far into the future, traditional techniques for dealing with uncertainty, such as characterizing that uncertainty with specific confidence intervals or significance values for point estimates, are of limited value. One of the ways to deal with systemic uncertainty is to create future scenarios based on different assumptions about the direction of current trends in supposed key drivers of the system. This was the approach taken by Delgado et al (2003) in their application of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model (Rosegrant et al, 2001) to the development of future scenarios of supply and demand in global aquaculture and capture fisheries. The model separates the determinants of demand for fish into price-mediated drivers, such as prices of substitute goods, and non-price mediated drivers, such as increased urbanization (which may increase demand for products from both sectors) or major ecological changes such as the collapse of fish stocks. Some of the scenarios modeled by Delgado et al include: a "baseline" scenario that includes what the modelers believe is the most plausible set of assumptions (where aquaculture production grows rapidly); a scenario in which the conversion efficiency of fishmeal and fish oil to edible farmed fish flesh improves dramatically; and a scenario called "ecological collapse," which is not defined explicitly in ecological terms but only narrowly by its consequences for annual output volume from the capture fisheries and from aquaculture. The ALCES (A Landscape Cumulative Effects Simulator) scenario analysis model (Schneider et al, 2003) provides another approach which might be adapted to situations involving multiple pressures on specific marine ecosystems. In all cases, scenario analyses require justifying the input parameters as well as the assumptions underlying trends expected in those parameters over the time scales of interest.

In the accounting framework, there needs to be room for the consideration of alternative future scenarios as a way of dealing with uncertainty about the structure and dynamics of the causal web in which the exposure and outcome variables of greatest interest are situated. From the case study of the GFASI, we discovered (as one example of many such discoveries) significant uncertainty about the nature of the link between regional/local scale ecological change caused by increased Peruvian anchovy fishing pressure and the proximate exposure of interest—the quantity and/or quality of fish available for consumption by Peruvians. Accounting for the uncertainty in this case would mean estimating the impact on the proximate exposure variables of various ecological realities, and also estimating the consequences of various mixes of "buffering" or mediating variables that stand between the ecological change and the proximate exposure variables in this segment of the causal web. Ideally, none of this estimation would be baseless conjecture, but based on existing knowledge of ecosystem dynamics, economics, and socio-political trends. For example, one scenario might play on the theme of income trends in Peru and the availability of imported fish products, and assume an increase or improvement in both; another scenario might assume a major downturn in global food fish production as fish habitat becomes unsuitable as a result of global warming. A major energy price increase, which would make energy-intensive fish processing cost-prohibitive, might also be included in a scenario.

In order for a fair comparison of different global industries, assumptions about certain ecological, economic, demographic, and socio-political trends affecting all peoples would need to be kept constant across industries, or varied consistently. Trends in the growth of each industry, its material and energetic demands, and the geographic distribution of those demands, would necessarily be industry-specific. Thus, for the GFASI, some of the industry nonspecific trend values that might be assumed would be a particular level of global demand for high-quality protein or a particular trajectory of energy prices. Discontinuous but significant events, such as political and social upheavals, could also be assumed, or else a probability could be assigned to their likelihood based on the presence of other factors or dynamics in those societies most relevant to the industry in question.

5.8. Valuing the distribution of population health impacts: whose health matters?

Accounting for population health impacts that stem from ecological changes caused by global industries implies that those impacts are geographically dispersed. The different population health impacts shown in schematic form in Figure 18., to which a particular global industry might contribute, will be realized in particular populations residing in specific socio-cultural contexts within identifiable political jurisdictions. In the GFASI, for example, we know that the grow-out phase of farmed Atlantic salmon production (as well as the actual consumption of farmed Atlantic salmon products) takes place largely in the northern hemisphere, with the important exception of Chile, and primarily in the affluent countries of North America and Europe. The production of fishmeal and fish oil, the primary inputs to the GFASI's production, is more geographically dispersed and includes, as we have seen, a large component from Peru. Although it has been beyond the scope of this study to evaluate the regional/local level ecological impacts of farmed Atlantic salmon production in the area of the grow-out operations in Norway, Canada, Chile, and other countries, an accounting framework that purports to account for all population health impacts stemming from ecological changes caused by the GFASI would have to recognize impacts in the countries where the farming itself is conducted. If there are currently some identifiable population health impacts associated with the GFASI's grow-out operations in, say, British Columbia, these impacts—whether positive or negative—should be included in the accounting process. This is assumed in Figure 18. but not made explicit in that diagram.

The health statuses of all of the different populations that may be affected by a particular global industry, whether through ecologically-mediated impacts at points of consumption, production, or input production, or through universal global scale ecological changes to which the industry contributes, may not have been equal prior to the onset of the industry or during its growth. Thus, the impacts that an ecological change of a particular type and magnitude will have on a population will be partly a function of that population's vulnerability. For example, measures of nutritional health indicate that Peruvians are less well nourished than Canadians (FAO, 2000). As a result, an incremental change in an ecologically related factor influencing nutritional status would be expected to have a greater impact in Peru than it would in Canada, simply because the nutritional status of many is already precarious. Thus, interpretations of information obtained through application of the accounting framework should be able to account for differences in the magnitude of the impact of a unit change in a health indicator that are related to the baseline health statuses of the populations affected.

The accounting framework is a tool for organizing and directing further research; decisions about what is just or needful in terms of public health interventions will require additional value judgments about the populations affected, the uncertainty with regard to the benefits (and who reaps them) and the harms or risks (and who bears them). Key public health principles of ethics such as autonomy, beneficence, doing no harm, and equity are all relevant to consideration of the ecologically-mediated population health impacts of global industries.

5.9. Industry-specific questions to guide the case study component of the accounting framework

The accounting framework requires that each assessed industry should first be subject to a case study process by which important definitional, historical, economic, geographical, and ecological features of the industry are characterized. A proposed set of questions for any global industry subject to assessment, intended primarily to guide the case study phase, is provided in Table 22. The types of answers needed to each of these questions are also indicated, as are notes on the value of obtaining this type of information (i.e., how it will help focus the remaining types of research aimed at determining the ecologically-mediated population health impacts associated with the industry being investigated). The questions proposed in Table 22. largely were drawn from themes that began to appear in material reviewed in the introductory and literature review sections of this study; additional questions arose through the process of working through the GFASI case study.

Table 22. Guiding questions for the case study portion of the accounting framework

Question	Type(s) of Answer(s) needed	Value of information
1. **What is the size of the industry, in dollar, material, EF, human labour, and other terms?**	Quantitative information; EF must include clear information about all assumptions made in internal calculations.	Aggregate EF helps determine contribution of industry to ecological sustainability of total human enterprise, and thus share of responsibility for consequences. Data on volume and types of materials and energy consumed by the industry help direct the process of disaggregating the EF and determining item-specific impacts.
2. **What are the key ecological, economic, and social/political/cultural dynamics in the industry? How do these dynamics focus data collection and analysis regarding impacts on health?**	Ideally, quantitative information on ecological and economic trends and key relationships between them; information on social, political, and cultural trends and events likely to influence ecological impact of industry (e.g., civil war, major new economic policy, rapid urbanization).	Over some time scales, economic relationships in the industry drive decisions about expansion, contraction, or distribution of operations; these characteristics bear on the size, timing, and magnitude of the ecological impacts of the industry. Information on major disruptive events and their likelihood also provides insight into the ways in which ecological conditions may be impacted.
3. **What are the shapes of the relationships of most importance in the industry?**	Quantitative information on relationships such as those between renewable raw material inputs and finished products, and between finished products and alternative, substitute products; information on important discontinuities in these relationships (e.g., absolute volume limits on a key input)	Trend data improves the quality of model inputs and the generation of likely scenarios based on the direction and interactions of trends relevant to the timing, size, type, and location of ecological impacts.

Question	Type(s) of Answer(s) needed	Value of information
4. **What, if any, plausible ecological catastrophes does the industry contribute to, and how?**	Nominal information with quantitative information on pressures, if available; for example, if the industry is a large emitter of greenhouse gases, the industry could be said to contribute to catastrophic ecological impacts associated with global warming, and quantitative information on the amount of greenhouse gases emitted by the industry would provide more information on the industry's contribution to catastrophic events associated with global warming.	Ecological changes that impact human population health can be of various types, including the incremental loss of ecosystem goods and services (such as may happen with desertification or loss of soil nutrients, leading to decreased food production) and the catastrophic collapse of ecosystems (such as may happen when major ecosystem elements, such as the consistent geophysical features of the oceans' thermohaline currents, are radically altered). The types of ecological changes with which the industry's operation is associated, and the nature of these associations, helps in the scoping of the investigation of related population health impacts.
5. **Which materials, and energy are being moved around globally?**	Nominal and quantitative information on the identity and actual movements of key inputs and outputs in the industry (e.g., steel, chemicals, agricultural produce).	The consumption of different types of materials and energy sources has different ecological impacts. The distribution of the geographic origins of these materials and energy sources, as well as the distribution of their places of transformation during production and their environmental fate, also determine the nature of their ecological impacts.

Question	Type(s) of Answer(s) needed	Value of information
6. What is the mix of renewable and non-renewable resources used in the industry, and how much of the latter are sustainably managed?	Nominal information on the relevant resources, along with volume of consumption and proportion that each resource constitutes in the total mix; some of this information will be needed for the EF calculation. Information is also needed on the quality (i.e., sustainability) of the management of the renewable resources (e.g., fibre) that are being used by the industry; this information is often neglected in conventional EFA.	The industry's contribution to changes in parameters at the global level (e.g., average global surface temperature) constitutes one mode of its ecological impact, as noted in the case study of the GFASI. Information on the management of the resources that the industry uses, and on the types of resources (as noted in Question 5.) can help determine the type and magnitude of the ecological impacts. For example, if two firms manufacture dimensional lumber using the same technology, but one firm uses only wood from a sustainably harvested forest, the ecological impacts of the two firms will be different.
7. What is the geographic distribution of production and of the impacts of production—are these all in countries other than those in which the product(s) is/are consumed?	Distributional information on the specific locations on Earth where the regional/local scale ecological impacts associated with the industry are taking place; this is essentially the information that would come from a "disaggregation" of the EF. Ideally, impacts would be pinpointed within the countries in which they occur, not just identified broadly by country of occurrence.	This information helps in the assessment of population health impacts associated with loss or change in ecosystem goods and services; it also is needed for evaluation of ethical principles such as autonomy and equity.

Question	Type(s) of Answer(s) needed	Value of information
8. How much impact, and what types and where, is likely associated with the illegal or "black market" aspects of the industry?	Detailed geographic and ecological information, as sought in Question 7 above.	Some industries are associated with large illegal, or unaccounted for, activities. Fishing, trade in animals and animal parts (furs, ivory, internal organs) and of course the substantial illicit drug trade are key examples. Not considering the ecological impacts of these related activities will likely underestimate the population health impacts of the industry. However, care is needed to determine which illegal activities are truly enabled by the legal industry, and which are not dependent on the operation of the legal industry.
9. What concurrent or parallel impacts are likely to interact with the impacts of interest—for example, in China where rapid industrial development has far-reaching ecological impacts?	Information identified in the answer to Question 2 above will assist in the answer to this question; also, information on the distribution of the impacts of the industry will indicate which areas should be investigated.	As with the above, the information implied in the answer to this question bears on the features of the ecological impact of the industry, especially as the impact of the industry over time, as growth or market distribution changes occur, is considered.

Question	Type(s) of Answer(s) needed	Value of information
10. **Where is the consumption of the products taking place?**	Data on rates of consumption of industry products at whatever level of geographic detail is available; for some products, data on ecological impacts of consumption and subsequent destruction of materials through landfill or incineration (or processes to recover usable materials or energy), will be warranted.	This information is relevant for evaluation of the distribution of the economic benefits of the industry, but also for the evaluation of the full range of ecological impacts, since some of these impacts are associated with transportation of the product to the points of consumption, and also with disposal or recovery of materials at the point of consumption.
11. **What is the distribution of wealth in the industry, and what are the trends in this regard?**	Data on the wealth of firms in the industry and on the distribution of shareholders' holdings in firms, if the firm is publicly traded; data on trends in wealth consolidation in the industry, such as corporate mergers, takeovers, and purchases and sales of firms or interests in firms.	This information is not strictly relevant to the process of identifying health impacts associated with ecological impacts caused by the industry, but it is relevant for any determination of the distributional equity of health benefits and harms associated with the industry, whether or not they are ecologically-mediated.
12. **What are the trends in technological development in the industry, and are changes likely to lead to less impact or more production, or both?**	Information and trend data on key technological issues in the industry that affect ecological impact (e.g., technologies affecting energy consumption and the consumption of materials in production).	Based on the I=PAT equality, changes in technology, given a constant level of consumption (Affluence) and a constant Population, means a change in Impact. Technological trends in the industry will figure into estimations of future ecological impact. If the industry expands and the consumption level changes, efficiencies realized through technological changes may be negated.

Question	Type(s) of Answer(s) needed	Value of information
13. **What specific questions of ethics are raised by this particular industry?**	Data on social and health impacts of the products of industry, and not necessarily just those stemming from ecological changes. Examples include the marketing of tobacco products, junk food, and personal vehicles with low fuel economy.	While this information is not strictly necessary to determining health impacts from ecological changes to which the industry has contributed, it is relevant to the determination of the equity in the distribution of all benefits and harms associated with the industry. It thus helps place in a larger context the benefits and harms stemming from ecological change.
14. **Given a plausible causal web linking consumption with production and ultimately with ecologically-mediated population health impacts, of what quality are the data on the variables in the causal web, and how accessible are these data?**	Information on data quality, for example: reliability of sources, information on accuracy of measuring devices or techniques used to obtain data, and likelihood of over- or under-reporting where relevant.	The estimation of population health impacts requires knowledge of the levels of uncertainty both about the relationships between the variables in the causal web that drive the ecological changes, and between the variables describing the ecological changes, the resultant exposures, and the population health impacts.

Question	Type(s) of Answer(s) needed	Value of information
15. **How deep and complicated is the layering of the "buffering" effect, and what are the implications of this for determining ecological impacts?**	Information on the identify, size, significance, or direction of the relationships hypothesized to exist in the causal system in which the industry is embedded; from a reductionist standpoint, the answer to this question is open-ended because the possibility for further clarification of causal and associative connections in the causal system is always present.	Complexity suggests the impossibility of knowing all the relationships between the parts, and thus suggests high levels of uncertainty in the prediction of effects. Models with even a small number of input parameters and small measurement errors quickly produce chaotic results after a few iterations; information on the complexity of the system (for example, the layers of ecological impact deferral through trade) helps determine how much useful information the population health impact accounting process is likely to yield.
16. **What are the specific externalities associated with the industry, and can they be accounted for in ecological, social, and other relevant terms?**	Information on all types of both positive and negative externalities associated with the industry, including estimates of proportional attribution in cases where harms would be diffusely realized (e.g., social costs of carbon)	Provision of a basis for full-cost accounting, which would in theory enable the market to play a more constructive role in reducing ecologically-mediated health harms, wherever they occur
17. **What are the demand, supply, and price elasticities associated with the major inputs to the industry, the products of the industry, and the complementary/substitute products to/for the industry?**	Data on trends in prices of inputs to, products of, and complementary/substitute products to/for industry outputs.	Because of the lack of direct negative (or positive) ecological feedback to many global industries, especially in the near future, production decisions by the firms in an industry are often dictated by relevant prices and by what those prices are predicted to be in the future. Thus, price information helps in the development of population health impact scenarios.

Question	**Type(s) of Answer(s) needed**	**Value of information**
18. **Are the industry and its products novel, such that knowledge of impacts, especially over time, may be relatively unknown or unpredictable? What does this mean for ecological and ultimately population health impact assessment?**	Information on the historical evidence for the production of products of this kind; the production of unusual or novel products may be associated with a greater degree of uncertainty about ecological impacts than the production of products with longer histories for which more data are available, or with a more limited or well-known ecological impact. Examples of products where the uncertainty of ecological impacts may be greater include products of genetic engineering and products of nanotechnology.	Information on the biological/chemical/physical behaviours of the inputs to the product(s) of the industry, as well as of the outputs of the industry, helps focus the search for links to particular ecological impacts. Uncertainties about the biological, chemical, and physical behaviour of the inputs and the outputs of the industry translates into uncertainty about ecological impacts; at the same time, unprecedented products about which we know little may be treated as more, not less, harmful than those for which we have more knowledge. This orientation is consistent with the Precautionary Principle.

5.10. Concluding notes on the development of an accounting framework

More work is needed to develop an accounting framework that would serve the purpose of facilitating the identification and quantification of the ecologically-mediated population health impacts, or ideally all population health impacts, attributable to the operation of a specific global industry. The main goal of the accounting framework as conceived in this study was to provide a means of comparing alternative human economic enterprises based on reasonable estimations of the contribution of those enterprises to human population health through ecological change. Relevant to any attempts at comparing alternative uses of resources are clearly articulated values around the equity of the distribution of the ecologically-mediated population health harms (or risks) and benefits identified in the accounting process, including explicit valuation of risks borne by future generations.

The accounting framework as described in the preceding sections may be criticized for requiring an extraordinary and unrealistic level of knowledge about the relationships between multiple parts of a complex system. There may be other more effective, practical, and scientifically defensible means of evaluating and comparing the ecologically-mediated, or simply the most tractable, human population health impacts to which specific global industries contribute. Two different but instructive examples of alternative approaches are evident in Huynen et al (2005) and Anielski (2004). In the context of this study, an important question to ask of each of these approaches, and of other approaches, is whether a particular industry such as the GFASI still could be assessed usefully in terms of its impacts on population health via ecological change.

Huynen et al (2005) propose a framework for assessing population health impacts associated with globalizing processes. They review existing frameworks for understanding globalization and health and for understanding the determinants of population health. Then, an attempt is made to incorporate the best features of these existing frameworks into an integrated model that is not overly complex. Three categories of health determinants, each of which may be affected by globalizing processes such as macro-economic policies, trade liberalization, and human movements (e.g., within countries to urban centres, or between countries) are identified: contextual determinants, distal determinants, and proximate determinants. In the Huynen et al model, "Environmental" determinants are "contextual" determinants. They include ecosystems and climate, and correspond to "Marine (and terrestrial) ecosystems at regional/local level" in our Figure 13. The ecosystems goods and services (see Table 2.) that these ecosystems provide are categorized as "distal" determinants—factors which are causally closer to population health states than underlying contextual features, but further away than proximate determinants. Proximate determinants include everything that has a direct impact on population health, from health care services to behavioural factors such as smoking and diet. In our Figure 13., the only truly proximate determinant would be "Amount and/or quality of fish available for consumption by Peruvians," although this claim would depend on the correspondence between these features of the total fish supply and actual consumption of fish.

Factors at all three levels in the Huynen et al framework are potential "buffers" of the ecology-human population health relationship shown in Figure 13. For example, we noted underlying factors such as cultural preference in Peru for white-fleshed fish, the trade in fish (e.g., importation of fish), and the potential for substituting other protein sources for fish in the daily diet should fish become less available. These factors are considered by Huynen et al as contextual, distal, and proximate determinants, respectively. It might be possible to examine the impact of a particular global industry (such as the GFASI) on each variable in a finite list of contextual, distal, and proximate determinants; however, such an approach would still not resolve problems of uncertainty, especially since, as Huynen et al note, complexity increases as one moves further away from the more proximate causes. In our example of the GFASI, one could research the individual health benefits or risks of consuming farmed Atlantic salmon, but it would be likely much more challenging to determine, with a meaningful degree of precision, the impact of the GFASI on many of the broad contextual determinants of health such as governance structure or the movement of people to urban centres.

The Genuine Wealth Accounting (GWA) model, developed and described by Anielski (2004), has been applied to jurisdictions such as the province of Alberta, Canada. The GWA is described as a method for helping organizations measure, assess and manage their "total wealth" or conditions of well-being, indicated by five types of capital: human, social, natural (ecological), produced (built or manufactured), and financial. The results of the Alberta study (Anielski, 2001) included a Genuine Wealth Balance Sheet consisting of measures of societal negatives (liabilities) and positives (assets) subsumed under each of the five capitals, as well as an equity component consisting of measures of the distribution of resources, wealth, and income in the province.

Because the GWA does not require the *a priori* proposition of any complex propositional web of causation, where uncertainty at any point seriously jeopardizes confidence in drawing strong epidemiological conclusions, it permits an assessment of societal well-being based on whatever data are actually available for measuring the well-being conditions germane to each of the five types of capitals which, independently and by their interdependence, exert primordial influences on the contextual, distal, and proximate types of health determinants proposed by Huynen et al (2005).

Within the component called human capital, the GWA system can account for specific population health measures such as life expectancy and rates of specific diseases. Thus, for example, if the prevalences of nutrition-related disorders were deemed a special concern in society, those measures could be incorporated into the accounting system and tracked over time. The GWA does not claim to link assets or liabilities to a specific cause or set of causes in an epidemiological sense, by looking at the historical connection between particular outcomes and exposures; instead, it focuses on tracking community well-being indicators over time. Eventually, time series data could lead to hypotheses about the variability in these outcomes and thus to more focused testing of relationships.

One final point that bears mention with respect to the accounting framework is the issue of the driving forces that affect the supply of, and demand for, the products of industry. Question 2. in Table 22. urges the investigation of this question as part of the initial case study component of the accounting framework. The economic policies implemented by governments at all levels, including those of international agencies such as the World Bank and International Monetary Fund, can strongly affect what goods and services are produced and where they are produced. In addition, effective marketing in a climate of ideological pressure for perpetual economic growth no doubt inspires the proliferation of products and services which are fundamentally unnecessary or even detrimental to human health and well-being. Thus, a more comprehensive accounting framework might look not only at the ecological and population health impacts of extant industries, but also describe and discuss the utility of the production and consumption of the products themselves.

Chapter 6. Discussion

6.1. Outline of this chapter

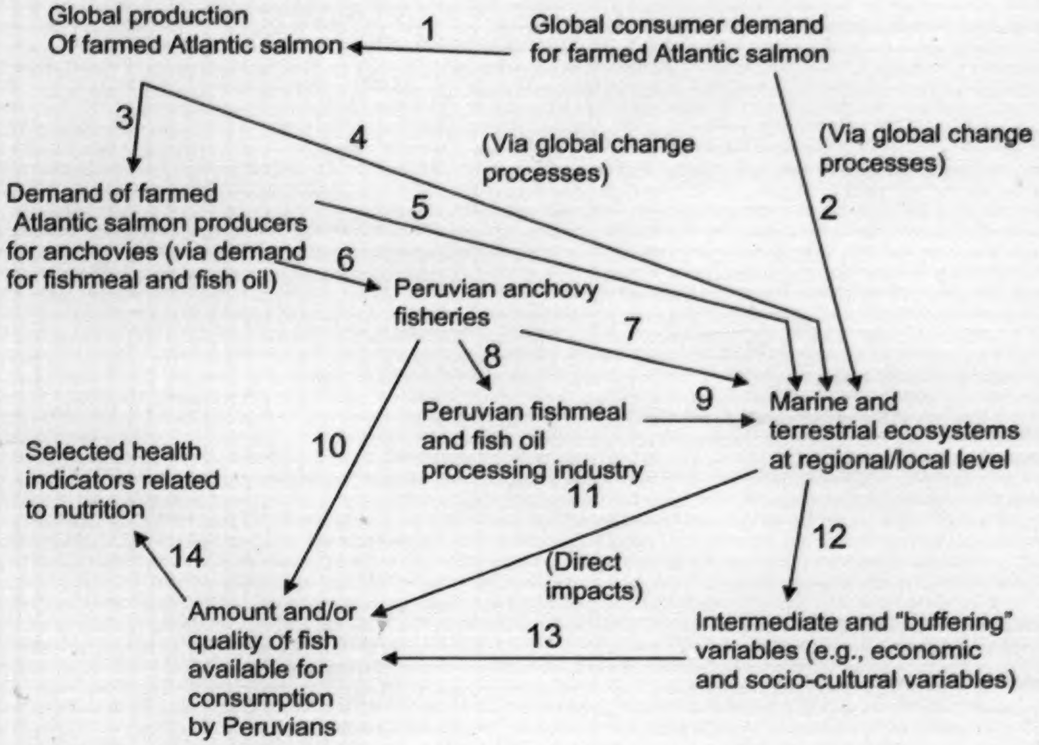
In this chapter we revisit the research proposition from Chapter 4, first pointing out a major problem with the proposition's construction and then considering and interpreting the evidence for and against the accuracy of the proposition with reference to the causal web in Figure 13. We also review gaps and shortcomings in our case study method, including analytical failures and omissions that would have improved the quality and meaningfulness of the investigation from an epidemiological perspective. Finally, we discuss challenges encountered in the development of an accounting framework for evaluating the ecologically-mediated population health impacts of individual global industries.

6.2. Revisiting the original research proposition

We began the case study investigation of the GFASI with this statement, which we termed our research proposition:

The global demand for farmed Atlantic salmon products has caused an increase in the global demand for farmed Atlantic salmon feed material. This demand has contributed to pressure for increased production of anchovies by the Peruvian anchovy fishery. Ecological changes stemming from this increased production and from downstream changes in the operation of Peru's fishmeal processing industry, as well as from global-scale ecological changes to which the global farmed Atlantic salmon industry contributes primarily by fossil fuel combustion, have caused changes in one or both of two key features of the total supply of fish available for human consumption in Peru since 1970: quantity and quality. One or both of these changes is significantly related to one or more nutrition related disorders in the Peruvian child or adult population.

Schematically, the system was envisioned as follows (Figure 13):


Global production
Of farmed Atlantic salmon
1
Global consumer demand
for farmed Atlantic salmon
3
4
(Via global change
processes)
(Via global change
processes)
2
Demand of farmed
Atlantic salmon producers
for anchovies (via demand
for fishmeal and fish oil)
5
6
Peruvian anchovy
fisheries
7
8
Peruvian fishmeal
and fish oil
processing industry
9
Marine and
terrestrial ecosystems
at regional/local level
10
Selected health
indicators related
to nutrition
11
12
14
(Direct
impacts)
Amount and/or
quality of fish
available for
consumption
by Peruvians
13
Intermediate and "buffering"
variables (e.g., economic
and socio-cultural variables)

Our research proposition was poorly conceived. The following discussion points out several specific flaws in the logic and assumptions of the causal web shown above; however, a more fundamental problem is the narrow focus of the proposition itself, which directs attention away from other, potentially more substantial, ways in which the GFASI impacts human health. As noted in section 1.8, economic activity that affects the provision of ecosystem goods and services in ways that have human health consequences is likely best viewed in a MEME (Multiple Exposures, Multiple Effects) context. Focusing on one source of one input (i.e., anchovies from Peru) to the GAFSI, as well as on a narrowly defined change in diet (i.e., a change in the quantity or quality of fish consumed) and several specific nutrition-related outcomes does not well represent this context. The accounting framework, developed mainly in Chapter 5 and discussed in section 6.3. of this chapter, better reflects an understanding of the MEME nature of the ecologically-mediated impacts on human health flowing from the activities of global-scale industries.

The link between global farmed Atlantic salmon consumption and production, and likewise between production and demand for anchovies, was assumed. However, the discovery of some important qualifications to these assumptions bears on any further investigation of these links. First, it is likely that consumers demand salmon, not "farmed" salmon, and most certainly not "farmed Atlantic salmon." In many retail environments, such as restaurants, consumers who order salmon may not know whether the salmon they are being served is wild caught or farmed, and if it is farmed, whether it is Atlantic salmon. In some markets (such as in the UK and northern Europe) there is a very high probability that farmed salmon will be of the Atlantic variety; but a more specific answer to this question—i.e., a clearer picture of the disaggregated consumption globally, as well as the knowledge that consumers have of what they are eating—would be beneficial for illuminating our claim that consumers "demand" farmed Atlantic salmon. While demand is normally understood in economic terms and quantified by sales, demand also has a psychological meaning. This latter meaning may be superfluous as far as the ecological impacts of the GFASI are concerned, but it is relevant should any interventions be made to change consumer attitudes or behaviour.

The causal web illustrated in the schematic indicates a direct link between the consumption of farmed Atlantic salmon and regional/local scale marine and terrestrial ecosystems in Peru. This link was included because we assumed that the consumption of farmed Atlantic salmon would place pressures on drivers of global scale ecological change, perhaps most importantly through the generation of greenhouse gases as a result of fossil fuel combustion in the transportation of farmed Atlantic salmon to the locations of consumption. We could not explore this connection in detail, and it is not well accounted for in our estimate of the GFASI's ecological footprint. The EF calculation was based on values from Tyedmers (2000); these values accounted for transportation of caught and farmed salmon to processing sites (this information was specific to British Columbia, Canada) but not from processing sites to end consumers. Line "2" in the schematic would not exist if line "4," which symbolized the relationship between the operation of the GFASI and its impacts on regional/local scale ecosystems in Peru via global scale drivers of ecological change, actually included all impacts related to the transportation of processed farmed Atlantic salmon products to their end consumers.

The nature of the connection described by line "4" in the causal schematic bears further investigation. Line "4" assumes that part of the way in which the GFASI affects regional/local scale ecological conditions in/near Peru is by impacting global scale drivers of ecological change (such as climate change), which ultimately affect regional/local scale ecosystems all over the planet. One of the areas of great uncertainty in the case study was how to treat the issue of the ecological sustainability of the GFASI, since the GFASI is one of thousands of global scale industries that contribute to humanity's overshoot of Earth's carrying capacity as affirmed by global EFA.

The GFASI does not actually demand Peruvian anchovies, as our research proposition and schematic indicate. Sales of fishmeal and fish oil to the GFASI, and the Peruvian anchovy content of that fishmeal and fish oil, would indeed show that the GFASI is demanding (again, in economic terms) Peruvian anchovies. However, we came to understand that some farmed Atlantic salmon producers within the GFASI, such as Norway and Iceland, are using fishmeal and fish oil in their feed pellets that contain no (or a negligible quantity of) Peruvian anchovies. The pressure that the GFASI exerts on the Peruvian anchovy fishery, by demanding fishmeal and fish oil made from processed anchovies, can still be estimated in the aggregate; but the assignment of responsibility for regional/local scale ecological impacts associated with the Peruvian anchovy fishery would be more accurate if it were broken down by producer nation, and possibly even by producer firm within each producer nation.

The link between demand for anchovy fishmeal and fish oil, and the Peruvian anchovy fishery, is taken for granted. As we discovered, the large majority of anchovies caught in Peru are reduced to fishmeal and fish oil, and part of that fishmeal and fish oil production is consumed by the GFASI. However, through the considerable volatility of the Peruvian anchovy fishery over the years of the GFASI's consistent growth (roughly 1970 through the present), it has rarely been a problem to market all the fishmeal and fish oil that can be produced. Large markets (e.g., terrestrial livestock producers) for anchovy-based Peruvian fishmeal and fish oil existed prior to the GFASI. While demand in these markets has varied (Delgado et al, 2003), nonetheless they continue to demand, now along with the GFASI, all the fishmeal and fish oil that Peru can produce. Thus, it is questionable whether the GFASI has exerted any *additional* pressure on the productivity of the Peruvian anchovy fishery and on the Peruvian fishmeal and fish oil processing infrastructure. Poultry and swine producers used to demand a large share of Peru's fishmeal and fish oil output, but these industries are incorporating increasingly more vegetable based ingredients into their feedstuffs. In addition, GFASI producers are experimenting with feed materials both that contain a lower proportion of fishmeal and/or fish oil, and which are more efficiently transformed into farmed Atlantic salmon biomass. Trends in these technological developments are important to keep in mind, and they are significant enough to affect the size of the demand that the GFASI places on the production of the Peruvian anchovy fishery and its related downstream processing infrastructure. It is also true that if the growth of the GFASI is in accord with optimistic predictions (i.e., around 2.5% per year for the next two decades), the production volume increase will overwhelm the substitution and efficiency effects of technological changes, which might otherwise have reduced overall ecological impact. Finally, on this point, the substitution of non-fishmeal/fish oil ingredients into farmed Atlantic salmon feed does not necessarily mean a diminishment of the total ecological impact of the industry, and by extension a diminishment of any negative human population health impacts associated with those ecological impacts; the increased use of vegetable-based proteins and oils, for example, would bring with it a different set of opportunity costs and ecological impacts.

The connection between the demand of the GFASI for anchovies and marine/terrestrial ecosystem change at the regional/local level (line "5") needs further exploration. The connection was initially included in the schematic because the causal web was originally intended to include demand for all reduction fish species, not just anchovies; as such, a share of the GFASI's contribution to regional/local scale ecological impacts in Peru would be expected to run not just through the Peruvian anchovy fishery but through other reduction fisheries of Peru—the sardine and mackerel fisheries, for example. The later, narrower focus on only the anchovy fishery of Peru made line "5" seem unnecessary. However, line "5" remains because some of the ecological impacts from the demand of the GFASI for anchovies would be expected to arise from the contribution of anchovies in fishmeal and fish oil from non-Peruvian sources (e.g., Chile, South Africa). Non-Peruvian sources would account for a very small proportion of the anchovies contained in fishmeal and fish oil consumed by the GFASI, and, in the case of non-Chilean fisheries, would constitute other subspecies of anchovy. Recognition of this element is important nonetheless, as it points to the need for thoroughness and clear scoping in further investigation of the system. It is reasonable to assume that pressures on the Chilean anchovy fishery in particular could influence the Peruvian anchovy fishery via the overlap of fish habitat and ecosystem processes between the two countries.

Our schematic assumes a direct link (line "10") between the size of the Peruvian anchovy catch and the amount and/or quality of fish available for consumption by Peruvians. The direct link was included because we believed that a reduction in anchovy catch would lead to a reduction in anchovies available for consumption by Peruvians. This seemed logical enough. However, the discovery that only small quantities of anchovies are consumed by Peruvians casts doubt on the direct nature of this connection. We were unsuccessful in locating data on the *per capita* or annual domestic consumption of anchovies not consumed in the form of fishmeal and/or fish oil. Direct domestic consumption of anchovies may change in the future, however, because of Peruvian government programs and policies aimed at encouraging Peruvians to eat more anchovies and to provide business incentives for the processing of anchovies for domestic consumption. Motives for these programs were not determined.

Our proposition also assumes a relationship between the size of the Peruvian anchovy fishery and the size of the Peruvian fishmeal and fish oil processing industry. This is taken as a given, mainly because the two industries show a strong historical connection, and also because shipping raw, freshly caught anchovies to foreign countries for processing would be economically and technologically prohibitive. However, we did not locate much information on the precise nature of the ecological impacts associated with the Peruvian fishmeal and fish oil processing industry, nor on the proportional contribution of that industry to the total ecological impact of the Peruvian anchovy fishery/Peruvian fishmeal and fish oil processing industry. Impacts of the latter were understood mainly in terms of releases of biologically and/or chemically toxic substances into the marine environment, but again, the details of this claim would need further exploration in a more complete examination of the research statement.

Our cursory exploration of the particular types of impacts on Peruvian marine ecosystems resulting from Peruvian anchovy fishing pressure (line "7") revealed several challenges for determining these impacts with any confidence. First, owing to the semi-predictable occurrence of ENSO events, there is very large natural variation in the size of the anchovy stock and in the geographical distribution of the anchovy stock in the ocean from year to year. Against this backdrop it is more difficult to determine the effect of anchovy fishing efforts on the population dynamics of the anchovy in the years of, and immediately following ENSO events. Second, any impacts predicted as a result of overfishing (assuming that the current catch, as currently regulated, is sustainable indefinitely) would have to come about because of a breach of regulations (i.e., illegal activity) or because the regulations were relaxed in order to allow a greater catch. There are indeed pressures for the Peruvian government to relax fishing regulations (for example, the generation of short term employment, short term income, and short term foreign exchange) but it is unclear if these economic and social pressures are, or could be in the future, sufficient to disrupt the conservation intent of the current regulatory regime in Peru. An important related question, which deserves exploration in a fuller investigation of this case study, is whether the current level of fishing effort is actually sustainable, and how that sustainability would be defined and measured. Third, the HCUE is so vast, and contains such a richness of aquatic life, that understanding the ecosystem to the point of predicting all of the impacts (or even those impacts most relevant to the present study's research proposition) from a change in the volume of one fish species extracted from the ecosystem, is unrealistic. The remainder of the causal web as conceptualized depends strongly on our ability to determine the type, magnitude, and temporal location of the ecological impacts predicted at this point—for example, those impacts that affect the multiple species of marine fish and other marine organisms consumed by Peruvians, and those ecological impacts that affect the socioeconomic conditions which contribute to the quantity and/or quality of fish available for consumption by Peruvians.

The existence of Line "11," which indicates the direct (i.e., unbuffered) relationship between the regional/local level ecological impacts and the quantity and/or quality of fish available for consumption by Peruvians, makes sense only if the assumption is made that the types and magnitudes of the ecological impacts actually translate into our food-related concepts of quantity and quality of fish. We were left with the question of whether ecological changes caused by overfishing anchovies would clearly lead to reduced catches of those marine species actually consumed by Peruvians (since anchovies are not directly consumed in quantity), or to a reduction in the quality of the marine organisms consumed by Peruvians, or both. This question was not explored in adequate depth.

We proposed that a large number of variables likely are included among the intermediate and "buffering" variables standing between the ecosystem changes and the amount and/or quality of fish available for consumption by Peruvians in the causal web. Twenty of these variables, noted in Table 10. in Chapter 4, are listed in Table 23. below.

Table 23. Buffering variables

Total fish products imports (Peru)
Exchange rates with countries from which fish are imported
Food aid from other countries or international organizations
Food aid from other countries or international organizations that includes fish products
Per kilogram price of fish in Peru relative to average of other substitutable sources of animal protein: chicken, pork, beef, mutton
Average proportion of household budget spent on food products containing animal protein
Internal food subsidies (Peru)
Internal fish products subsidies (Peru)
Per capita internal monetary social support (Peru): transfer payments, emergency relief
Socio-cultural preferences for fish consumption
Socio-cultural preference for anchovies as human food
Gross Domestic Product in Purchasing Power Parity (PPP), *per capita*, Peru
Balance of Trade, Peru
Amount and proportion of Peruvian GDP for which all fisheries, and the anchovy fishery in particular, are responsible
Implementation of economic policies implemented under Alberto Fujimori (in power 1990-2000)
GINI (income equality)
Population (Peru)
Urban population as a proportion of total population (Peru)
Age structure of population (Peru)
Daily per capita caloric intake from animal products

The fundamental issue at stake in the part of the causal web described by lines “12” and “13” is how the myriad dynamics of political organization and power, economic policies, trade, international relations, demographics, and socio-cultural realities act to determine how a regional/local level ecological change, or complex of changes, finally impacts certain portions (in our case study, the quantity and/or quality of fish) of the domestic food supply available to the populace. Several of the variables in Table 23. reflect the power of money, and of economic policies that affect the distribution of wealth domestically and internationally, to buffer domestic ecosystem impacts via importation of those goods for which domestic production has been affected by loss of regional/local ecosystem productivity. Essentially, the issue is whether or not a needed good can be obtained from elsewhere when it is not available domestically. Three factors are relevant: (1) the good in question exits; (2) the seller (or donator) is willing to part with the good; and (3) the buyer has enough money to pay for the good if it is being sold. The availability of fish for consumption by Peruvians is affected not only by the ecological conditions that influence the domestic production of fish, but by the ecological conditions that affect the global production of fish, since the flow of imported fish depends on the integrity of the marine ecosystems that support the various fisheries providing the imported product. This is why the proposed causal web that we have been exploring is not closed but open, in both economic and ecological terms. Whether or not changes to the bioproductivity of the HCUE result in a reduced quantity or quality of fish for Peruvians does not depend solely on what happens in that particular ecosystem, nor solely on what happens to that ecosystem as a result of pressures induced by one specific global industry, the GFASI. Recent research by Worm et al (2006) points to an almost total exhaustion of organisms fit for human consumption from the Earth's oceans by 2050, owing to major marine ecosystem changes induced by unsustainable fishing pressure worldwide. Countries such as Peru, whose citizens on average have substantially less purchasing power than citizens of the wealthiest nations, are expected to experience the population health consequences of a shortfall in global food fish availability sooner than countries with more money to spend in international markets.

Line "14" in the causal web schematic proposes that the amount and/or quality of fish available for consumption by Peruvians contributes causally to certain nutrition-related health outcomes (such as stunting in children) in the population. The case study revealed that there are likely variables lying between the exposure (quantity and/or quality of fish) and the outcome (e.g., stunting) in the causal pathway. For example, the presence of other foods in the diet and the total caloric intake of the exposed persons are relevant. Clarification of the role of these variables may be possible by isolating the effect of different dietary constituents on different nutrition-related endpoints.

Broad changes in dietary intake have been taking place throughout Latin America in the time since the onset of the GFASI's expansion. Differences exist between rural and urban dwellers, and among the numerous subcultures in the region. In Peru, the aggregate data show that *per capita* fish consumption has changed little during this period; the low variation would make it difficult to detect a relationship between fish consumption and nutrition-related disorders even if a plausible causal connection were hypothesized.

6.2.1. Gaps and shortcomings in the case study method as applied in this research

The case study method proved to be a useful means for discerning the broad contours of the GFASI's impact on human population health via its contribution to ecological change, and thus for suggesting places where more focused research would be valuable. The above discussion of our research proposition, in light of the results of the case study, shows that the case study method as applied in this research could not provide conclusive information about many of the relationships believed to exist in the causal web; it could only point to areas where further investigation would likely enable more certain conclusions to be drawn.

The case study started with a research proposition (i.e., that the system of relationships described in Figure 13. accurately characterized one specific part of the operation of the GFASI in the observable world) which seemed reasonable at the outset of this study but which was not supported by much empirical evidence. Consequently, questions about the accuracy of the conceptualization of causes and effects arose at almost all points in the causal web. The literature was difficult to navigate, because studies which were relevant for clarifying specific relationships in the causal web did not have the larger picture in view when they were conducted. This created uncertainty about the temporal connections in the causal web. For example, there is evidence to show that production in the Peruvian anchovy fishery is related to production in the Peruvian fishmeal and fish oil processing industry, but it is unclear how demand for Peruvian fishmeal and fish oil by the GFASI contributes to the dynamic between the Peruvian anchovy fishery and the Peruvian fishmeal and fish oil processing industry, especially in light of recent changes in Peruvian policy to increase direct domestic human consumption of anchovies. In short, the sound but narrow scientific studies and the non-scientific literature that contributed to the resolution of the case study could not, in the context of the limited analysis done in this study, answer the systemic question that we posed.

This study showed that it is not unreasonable to infer that attempting to identify and to quantify the ecologically-mediated population health impacts caused by a global industry by constructing, one-by-one, a very large number of complex causal proposals or hypotheses that all would have to be valid in order to explain all of the impacts of the industry, and then investigating the implicit and explicit assumptions at every point in each and every one of those causal propositions, sets up an impossible task. This is a task comparable to that of federal chemical assessment agencies that must evaluate the "safety" of chemicals being proposed for industrial production and distribution in society. The end result is that only a minute fraction of the chemicals that need to be analyzed are analyzed; the number and variety of tests performed on those chemicals is severely limited, given the multiplicity of ways that the chemicals can act to harm the human organism; and the adequacy of the toxicological models used in the testing is always suspect. However, answering certain questions, such as those listed in Table 22., may point researchers to those areas of ecological impact which, for a specific industry, are likely to be most significant to human health. These areas would then become priorities for investigation. Ideally, a transdisciplinary approach (see section 7.3.) would help in the identification of these most significant ecological impacts, and reduce the amount of misguided research.

6.3. The accounting framework

The development of a useful accounting framework was hindered by the uncertainty associated with determining population health implications from knowledge only of ecological impacts. Even the latter may be very difficult to pinpoint, and the development of comprehensive indicators of ecological integrity (as opposed simply to measurements of the quantity of discrete material resources in an ecosystem) to which human health is sensitive remains difficult. The case study of the GFASI showed that the buffers between ecological impacts and population health impacts are numerous and of different types, and those buffering variables are likely to vary by context. Still, international trade is predicted to play currently, and continue to play, a very important role in the buffering process. In the GFASI example, access to imported fish affects the total supply of fish available for consumption by Peruvians, and it also helps determine the quality of that fish. A similar import effect would likely be present in a different industry, though the material imported could be rice or timber or cotton.

Estimating the human health consequences of global ecological overshoot, and allocating a measure of responsibility for those consequences to a particular industry (based on that industry's EF) entails the application of knowledge about impacts on particular ecosystems (the location of which would be derived from a disaggregation of the EF for the industry). However, it also requires knowledge about certain of Earth's ecosystems which are being impacted because of global scale drivers of change (such as climate change) to which the industry contributes. EFA involves an evolving, complex set of assumptions and calculation methods based on ecological principles about which our knowledge is still growing, and the extension of EFA to account for time- and location-specific population health impacts downstream from time- and location-specific ecological impacts is a substantial methodological leap if not a conceptual one. Throughout the development of the accounting framework, we encountered many areas of human ignorance about the workings of ecosystems over multiple time scales and the accuracy with which specific ecosystem impacts on Earth can be attributed to specific drivers and pressures (for example, the pressure exerted by a single global industry). Further, since so little is known about the relationships of interest, decisions for dealing with uncertainty in the accounting framework (shown in Table 21.) were almost arbitrary. The accounting framework, like the case study method, can point to places where data collection, research, and analysis are needed, but it cannot enable a quantification of the level of human suffering, indicated by morbidity and mortality rates for certain conditions, resulting from impacts on Earth's ecosystems for which particular global industries are responsible. As the case study showed, all of these impacts are moving targets. The system of forces in which human activities are embedded is largely unchartable.

Specific concerns with the development of the accounting framework were several. A short list of major difficulties follows, with a brief discussion of each.

6.3.1. The concept of the accounting framework

Unlike accounting for the flows and stocks of money in a corporation or a society, accounting for the ecologically-mediated impacts on population health which are attributable to the actions of specific actors necessarily involves several domains of scientific knowledge and methodological expertise. Population health, or even a global concept like the total burden of disease, is not (like money) a fixed quantity that changes hands or of which the total supply may be increased by government decree; rather, the total "amount" of population health or of the disease burden can increase or decrease. Ecological integrity is a similar entity: the loss of ecological integrity in one part of the Earth does not mean an equivalent gain somewhere else. Additionally, the flow through an industry of money, and materials and energy valued in money terms, is typically tracked, whereas the ecological impacts, and the population health impacts stemming from the ecological impacts, are not tracked. The population health "accountant" who wishes to determine the ecologically-mediated population health impacts associated with an industry must seek data which may be only indirectly related to the quantities and qualities of interest. Thus, without substantial change in the accounting demands placed on global industries, even rough predictions of the ecologically-mediated population health impacts of these industries, in terms meaningful to epidemiologists and other scientists and useful for policy-makers, are difficult to make. Arguments for the imposition on corporate enterprises of a much more comprehensive scheme of accounting that includes ecological and related population health impacts are convincing from a public health standpoint, but beyond the scope of this study to explore.

6.3.2. Limiting the accounting to population health impacts associated with ecological change

It has been stressed that the most obvious factors buffering the relationship between negative ecological impacts and human health are those related to trade, and implicitly, to money. If the distribution and actual use of money in society is not incorporated into the accounting, such that only impacts on human health directly caused by ecosystem change are accounted for, the total impact of the industry on human health may be underestimated. The accounting would then only include (for example) impacts on populations who rely directly on a food source destroyed by ecosystem degradation; populations that suffer disease or death because of a flood induced by a warmer global climate to which an industry has contributed via its combustion of carbon-based fuels; or populations that suffer injury or death because an industry has reduced the EI of an ecosystem providing a physical buffering service against natural stressors such as tsunamis. Potentially important factors in the determination of the population health impacts of an industry would be missed if the purchasing power or income of the populations affected is not incorporated—such as the inability of poor persons to purchase imported goods if an ecological event or incremental loss of biocapacity has depleted local markets of needed products. These effects would be missed if the accounting considers only gross exposure measures such as the total food supply, which could consist disproportionately of imported foods, and not the actual power of the relevant populations to access those foods. These factors may be substantially attributable to the industry; for example, export-oriented commercial fruit production may both reduce access to wild or traditional foods that would otherwise have been harvested from the ecosystem which has been appropriated for export production, and increase or decrease the amount of money that workers on the fruit plantation have at their disposal (compared to their previous employment) for the purchase of needed goods and services.

6.3.3. Attributing specific ecological impacts to specific industries

Investigation of ecologically-mediated impacts on population health caused by specific industries takes place in a MEME (Multiple Exposures, Multiple Effects) context. As such, designating precise individual industry responsibility for individual outcomes is impossible in most cases, especially when there are significant time lags between the contributing factors and the outcomes.

According to Costanza and Wainger (1993), complex systems violate the assumptions of reductionist techniques and therefore are not well understood using the perspective of classical science. Economic-ecological systems are complex systems. One of the most difficult challenges for an accounting framework that aims to help identify the ecologically-mediated population health impacts attributable to a specific global industry is the challenge of determining when, where, and through what mechanism(s) current, measurable activities (such as the emission of a certain quantity of CO_2, or the annual destruction of a certain area of wetland that may relatively simply be attributed to a particular global industry) will have their impacts on population health. We have noted this problem earlier, but its significance to the development of an accounting framework has not been considered.

Two concerns are especially important in the context of an accounting framework. The first is that global industries, along with small-scale activities and background climatological changes, contribute to changes in broad features of the biosphere. These include changes of tremendous importance to the livability of Earth for humans and other life forms, and include: changes in major ocean currents such as the Gulf Stream; raised sea level; differential changes in precipitation, land temperature, and the length of growing seasons, leading to changes in the productivity of agriculture (Walther et al, 2002); and changes in the intensity, frequency, and distribution of extreme weather phenomena such as hurricanes, torrential rains, and heat waves (Meehl and Tebaldi, 2004; Easterling et al, 2000). The absolute and relative contributions of each of these factors is regularly debated and is a source of controversy, as is the contribution of any single global industry (or nation, or other entity) to these changes (Cazorla and Toman, 2000). Each of the ecological or climatological changes noted above portends substantial, or catastrophic, health impacts for some human populations. However, the absence of historical data and the probabilistic nature of the phenomena in several dimensions prevents the assignment to any specific global industry of direct responsibility for related population health impacts.

The second issue is the scoping of industrial activity. Accounting for all of the positive and negative ecological externalities for which an industry is responsible would require an unrealistic amount of research for some industries, but there would be challenges to the usefulness of the results, in the political sphere, of an application of the accounting framework should the frame of responsibility for these externalities be drawn either too conservatively or too liberally. Erring on the side of the former may lead to a situation where health-affecting ecological impacts associated with an industry are overlooked. With no particular industry responsible, the range of politically sensible means (such as invoking a version of the "polluter pays" principle) for addressing or preventing harms to health is reduced. Erring on the side of liberality or over-inclusiveness makes less credible any claims about the depth of the responsibility of any one industry for certain ecologically-mediated population health impacts. While Table 18. provides some guidelines for what to include in the accounting, more specificity is needed and the application would need to be consistent.

Chapter 7. Recommendations

7.1. Outline of this chapter

The core of this chapter is a table (Table 24.) where recommended directions for further research are presented in the form of questions. Table 24. includes the basic goals of the identified research needs as well as specific types of research which could meet these goals. Benefits are then discussed of a transdisciplinary approach to problems such as those explored in the present study, followed by a review of several issues of ethics relevant to population health impacts associated with ecological change. Finally, several other potentially fruitful approaches to research in the eco-health field are considered, and specific data and information needs are identified.

7.2. Recommendations for further research

Our case study and the process of developing the accounting framework raised numerous questions and revealed knowledge gaps and needs for improved methods that further research could help remedy. New questions would no doubt also be raised in the process.

The goal of the broad range of research recommended below is to gain scientific knowledge and improve methods for the investigation of eco-health questions that require thinking in terms of complex systems. Table 24. indicates important gaps in knowledge or methods in the form of questions, the immediate goals of improving knowledge and/or methods in these areas, and recommendations for relevant types of research to accomplish these goals.

The knowledge and methods gaps in Table 24. are grouped into several categories representing central concerns in this research: (1) gaps related to the determination of population health impacts associated with ecological changes attributable to the GFASI, especially in Peru; (2) ecological impacts of the activities of global industries; (3) important features of the global distribution of human health risks and benefits associated with changes caused by global industries to the ecosphere (e.g., climate change), to the quantity and quality of ecosystem goods and services in specific locations on Earth, and to regional/local level EI; and (4) needs for improved methods for approaching these questions.

Table 24. Recommendations for further research

Knowledge or methodological gap	Goal of research in this area	Recommended research
Population health impacts associated with ecological changes attributable to the GFASI, especially in Peru		
1. How does the global distribution of ecological impacts that reduce the quantity and/or quality of ecosystem goods and services, and/or ecological integrity, and which potentially create population health risks, compare between farmed Atlantic salmon and other modes of obtaining reasonable substitutes (e.g., fishing for wild salmon, fishing for other, comparable species, farming other comparable species)?	Improved ability to evaluate equity in the distribution of established or potential population health risks attributable to ecological impacts of both the GFASI and alternative ways of obtaining similar nutritional benefits. This could expand the range of useful information for informing policy related to each of the industries and to broader goals, such as global food security, of international agencies.	Disaggregation of the EF of the GFASI and of the industries to be compared, at the greatest resolution practicable, in order to determine specific populations bearing health risks from ecological change; determination of the relative ability of these populations to buffer health risks; tracking of money flows in the GFASI and in the industries to be compared (i.e., which persons, firms, and populations are benefiting financially from the enterprise, and where and in what population health context these entities are located).

Knowledge or methodological gap	Goal of research in this area	Recommended research
2. What is the nature of the relationship between the GFASI's demand for fishmeal and fish oil and the ecosystem changes caused by the fisheries providing these feedstocks?	Ability to tie GFASI production levels with the loss of specific ecosystem goods and/or services and/or EI, improving the possibility of full-cost accounting and incorporation of ecological changes, and population health risks and benefits, into the cost of production (and into the price) of farmed Atlantic salmon.	Determination of several features of, and trends in, the demand of the GFASI for fishmeal and fish oil in relation to other consumers of these products—for example, total demand by volume and broken down by species and by organismic quality within these species; trends in the proportion of the global production of fishmeal and fish oil consumed by the GFASI and by other consumers of these products; and indicators of the health and relative importance by share of total global production, of the ecosystems providing the fishmeal and fish oil consumed by the GFASI.
3. To what extent does the GFASI's demand for fishmeal and fish oil (for all fishmeal and fish oil exporting countries from which the GFASI buys product) affect changes in the proportion of the national supply of dietary protein that is imported by fishmeal and fish oil producing countries (such as Peru)?	Improved ability to assess the GFASI's role in increasing the vulnerability of populations in other nations to the dictates of the global food market	Needed are various types of market related research and research into the history of food and nutrition in countries and among vulnerable subpopulations; also needed are geographies of trends in the international movement of nutritious foods from poorer countries to richer countries and vice-versa, with a focus on comparing trends in the protein foods consumed with dollars received from the export of protein foods (i.e., small pelagic fish) produced domestically.

Knowledge or methodological gap	Goal of research in this area	Recommended research
4. What proportion of the EF of the world's total food production is attributable to the GFASI, and how is this proportion changing?	Better data for determining (protein) energy return on investment (EROI) and thus for making food production and consumption choices, and improving the accuracy of the pricing of these foods, based on global ecological (energetic) realities.	Determination of denominator (EF of global food production activities, including aquaculture); determination of numerator (EF of GFASI); comparison of changes in this proportion over time, and comparison with changes over time in the share-of-EI proportions of comparable foods.
5. Related to (4), what is the sustainability of the specific ecosystems from which the GFASI is drawing resources, in contrast to the "global hectares," based on the average productivity of different land and water types, that are assumed in the calculation of the EF?	Improved capacity to make food production decisions at scales for which there is institutional capacity; global values for EF can obscure important regional differences both in the sustainability of the ecosystems from which resources are drawn, and in the relative demand for those resources (i.e., the distribution of consumption).	As with Question (1), disaggregation of the EF of the GFASI is needed, as are analyses over time of the features of these specific ecosystems that contribute to their sustainability over time, using the best indicators available.
6. To what extent are consumers of farmed Atlantic salmon aware that they are consuming a farmed (as opposed to a wild caught) product?	Improved potential for effective intervention at the level of consumer choice and public education.	Appropriately focused survey research.
7. What effects do the reduction fisheries in Peru have, via ecological changes, on the quantity and quality of those fish species preferred as food by Peruvians?	Improved capacity to assess the impact of an important fishery to the GFASI on the whole complex of marine species constituting the domestic fish supply.	Field ecological research on relationships between key species in the HCUE, including prey of, predators on, and competitors of the species of fish targeted for reduction.

Knowledge or methodological gap	Goal of research in this area	Recommended research
8. How does growing consolidation of ownership and wealth in the GFASI affect income equity in the various countries that participate in the GFASI?	Improved ability to determine and assess potential health-impacting features of the GFASI not directly related to ecological change.	Tracking of changes in the GFASI related to loss or gain of employment and wage-earning opportunities, number and relative power of shareholders in publicly-traded firms within the GFASI, the geographic distribution of firms and ownership in the GFASI, and other features relevant to the distribution of wealth within the countries that produce farmed Atlantic salmon.
9. Which farmed Atlantic salmon producers consistently use fishmeal and fish oil purchased from Peru, and which consistently use fishmeal and fish oil derived from fish caught in waters under the jurisdiction of nations currently without major nutrition-related population health problems? This question is related to Question (3) above.	Improved understanding of which GFASI nations are appropriating ecological capital that directly produces goods which might otherwise provide population health benefits to the regional/local population.	Research similar to that conducted for Question (3), and related to information obtained through the disaggregation of the EF of the GFASI; review of relevant trends in the nutritional status of populations in nations providing fishmeal and fish oil to the GFASI.
10. What are the ecological connections between the fisheries of the world devoted to catching fish for reduction into fishmeal and fish oil, and the planet-wide degradation of marine life-support systems and biotic richness?	Improved understanding of the contribution of fisheries mismanagement not only to one specific regional/local ecological change which could impact human population health, but to other changes in the global marine environment that may result in impacts in other regions and on other populations.	Extensions of recent research into global marine ecological change (e.g., Worm et al, 2006)

Knowledge or methodological gap	Goal of research in this area	Recommended research
11. What has been the impact of the anchovy (and all reduction fish) processing plants in Peru on the integrity of the coastal marine environment—specifically, on the net primary productivity of the HCUE and on the health of the organisms in the ecosystem?	Extension of knowledge about the variety of distal regional/local level ecological impacts associated with the production of key inputs for the GFASI.	Determination of all effluent chemicals from plants and measurement of chemical presence and/or markers of chemical activity (such as impacts on indicator species) in appropriately sampled areas of the coastal marine environment.
12. Which GFASI producer nations buy fishmeal and/or fish oil from Peru, and how has the market for Peruvian anchovy-based fishmeal and fish oil (specifically for farmed Atlantic salmon production) changed throughout the GFASI's history?	Improved capacity to attribute drivers of ecological and human health changes associated with the production of Peruvian anchovies for use by the GFASI.	Review and synthesis of relevant industry information.
13. In what ways will climate change affect the exposure variables of interest in this study: quantity and quality of fish available for consumption by Peruvians?	Improved capacity to assess the GFASI's contribution to changes in the exposures of interest; also, improved knowledge for assessing impacts of climate change on other food and nutrition-related variables.	Development of scenarios of marine ecosystem productivity and fishing effort, based on best available estimates of trends in global warming and fishing effort, in areas where fisheries providing fish to Peru are located (whether domestic or international).

Knowledge or methodological gap	Goal of research in this area	Recommended research
14. What impacts have national (Peruvian) and international policies had on the supply of fish available for consumption by Peruvians?	Improved understanding of the human context in which ecological factors affecting fish supply are embedded, through determination of institutional and political factors relevant to the proximal exposures of interest (quantity and quality of fish available for consumption by Peruvians) in this study.	Selective legal, political, and economic histories; special focus on the productivity of the Peruvian fisheries and the dedication of processing plants for specific end uses, as well as on Peruvian import and export trends in fish products.
15. What characterizes the economic development path that Peru has chosen with respect to its fisheries, and what effect has this path had on domestic fish supplies?	Improved understanding of the role of (historical and current) economic policy on the quantity and quality of fish available for consumption by Peruvians.	Review and analysis of economic policy, trade statistics, and other relevant information.
16. What are the historical elasticities of demand and cross-price elasticities of demand for protein-dense food products traditionally consumed by Peruvians?	Improved understanding of the role that consumer income and relative prices in Peru play in household decisions about consuming fish.	Review, analysis, and synthesis of economic data.
17. What is Peru's current trade balance in fish protein for human consumption, and how has this trade balance varied in the years since Peru first began exporting and importing fish?	Improved understanding of Peru's potential for improving nutritional health through domestic resources.	Use of accurate and comprehensive fish production and trade data to calculate trade balance in fish protein; analysis of factors contributing to changes in this trade balance from year to year.

Knowledge or methodological gap	Goal of research in this area	Recommended research
18. What would the EF of the GFASI be if all of the fish used for the production of the fishmeal and fish oil used in the industry were caught only from the respective domestic waters of the countries producing the farmed Atlantic salmon?	Improved information on the ecological implications of alternative scenarios to the "business-as-usual" supply arrangements prevailing in the GFASI.	Scoping of GFASI fishmeal and fish oil input requirements based on extant or potential reduction fisheries in the fishing waters of the countries of farmed Atlantic salmon production; analysis of the relevant ecological impacts from the predicted level of fishing required; calculation of the EF of the GFASI based on these alternative sources of input supply.
Ecological impacts of the activities of global industries		
19. Are there examples of countries (or regions) which limit buffering activities such as trading for imported goods, in order that appropriate biophysical constraints to population size and affluence at the regional/local level might affect production decisions?	Improved understanding of alternative models for regional sustainability and of practical integration of feedback on the health of ecosystems and the level of ecological integrity into production and consumption decisions.	Case studies.
Features of the global distribution of human health risks and benefits associated with changes caused by global industries such as the GFASI to the ecosphere (e.g., climate warming); to the quantity and quality of ecosystem goods and services in specific locations on Earth; and to regional/local level EI		

Knowledge or methodological gap	**Goal of research in this area**	**Recommended research**
20. What is the South (production) to North (consumption) trend in the movement of fish biomass during the past two or three decades of expansion in global aquaculture or, more specifically, farmed Atlantic salmon production?	Improved understanding of trends in the transfer of specific ecosystem goods which are beneficial to human health (e.g., fish) from poorer to richer nations via the international market; determination of whether aquaculture or subsectors of aquaculture such as Atlantic salmon farming have resulted in a net transfer of biomass from the South compared to periods of non-industrial level aquaculture.	Review of historical catch data and data related to imports and exports of fish; answering the question at the individual country level may be more feasible (i.e., what are the features of the movement of fish biomass from Peru to countries that are relatively wealthier)?
21. How is the GFASI characterized in terms of the distribution of wealth associated with the sale of its products, and how does this compare to the distribution of wealth in the global wild salmon fishery, both before and during the period of the GFASI?	Determination of features of the GFASI relevant to its impact on population health via wealth-related mechanisms; also, determination of the distribution of benefits flowing from an underlying net impact on ecological health.	Quantitative review of the trend towards consolidation in the industry, and tracking of money flows within FAS conglomerates, from wholesale and retail sales of FAS products to industry worker and shareholder compensation; comparison with results of similar review of the wild salmon fisheries of the world.

Knowledge or methodological gap	Goal of research in this area	Recommended research
22. What (if any) effects has the GFASI's demand for fishmeal and fish oil from Peruvian sources had on the distribution of wealth within Peru, especially as compared to the distribution of wealth within those Peruvian fisheries devoted to the capture of fish for direct human consumption, and as compared to the reduction fisheries if various proportions of their output were instead marked for direct human consumption and sold within Peru?	Development of insight into the comparative impacts on internal income distribution of export-oriented feed fish production, domestic food fish production, and the re-direction of export-oriented feed fish output to direct, domestic human consumption; this information could then be related to the comparative ecological impacts of each type of fishery.	Historical review of the movement and distribution of wealth in the Peruvian fishmeal and fish oil industry; development and evaluation of alternative scenarios involving the direction of different proportions of reduction fish (or of entire species) to domestic (within Peru) human consumption. Various kinds of market analyses also would be required.
23. With international trade and other, wealth-related means of buffering the effects of negative regional/local scale ecological impacts being so ubiquitous, is the expression, "ecologically-mediated population health impacts" conceptually and practically useful in future research?	More refined and clearer operational definitions of key terms and expressions used in research in this area; improved opportunities for the translation of key concepts between and among disciplines in a transdisciplinary research context.	Experimentation with different operational definitions in various research endeavours, with ongoing peer review; use of case studies, where regional/local scale ecological change has been profound and is directly attributable to one or more global industries, to improve understanding of the ways in which ecological conditions affect health in specific contexts; development of terms and definitions in concert with the development of indicators of the status of ecosystems and of population health.

Knowledge or methodological gap	**Goal of research in this area**	**Recommended research**
24. What is the relationship between anthropogenic emissions of CO_2 and the frequency and geographic distribution of extreme weather events?	Increased knowledge of the relationship between anthropogenic contributions of CO_2 to the atmosphere and the frequency and geographic distribution of extreme weather events; better estimates of the social cost of carbon and of the population health implications of making changes to CO_2 emissions.	Various types of climate modeling using best data available; correlational analyses for the development of more specific research hypotheses.
Effective methods for research		
25. How can methods be improved for determining and interpreting relationships between certain industrial activities and ecological impacts?	More accurate and defensible means of attributing specific ecological impacts to specific industrial activities.	Theoretical and practical work to adapt and apply the DPSEEA framework to global scale industrial activity; further application and refinement of epidemiological techniques used for MEME situations.
26. How can methods be improved for determining and interpreting relationships between certain ecological consequences caused by industries and the population health implications of those ecological consequences?	More accurate means of attributing specific ecologically-mediated population health impacts to specific industrial activities.	Testing of the suitability and value applying other analytical techniques not employed in the present study, including SEM, GM, multi-level modeling, and techniques developed through transdisciplinary collaboration.

Knowledge or methodological gap	Goal of research in this area	Recommended research
27. How can methods for corporate "five capitals" accounting, including accounting for the contribution of specific industries to changes in the subcomponents of the five capitals, be improved?	Improved information base for evaluating performance of specific industries in relation to societal population health and well-being objectives.	Epidemiological research on the five capitals as determinants of health in populations, so that population health impacts associated with levels of the different subcomponents of these capitals can be estimated; critical review of current data collection and organization structures and processes for indicators of the status of the subcomponents in each of the five capitals.
28. How can the case study method be improved?	More efficient exploration of case studies of global industries and improved chances for the generation of testable hypotheses from the case studies.	Review of relevant electronic databases and development of a literature search algorithm for the conduct of the literature review portion of the case study.
29. How can methods in transdisciplinary research be improved?	Improved synthesis of contributions from different involved academic disciplines.	Review of theoretical underpinnings of relevant disciplines and translation of discipline-specific concepts into terms relevant to research objectives.
30. What ethics for dealing with uncertainty about ecological and population health impacts, and their attribution, need to be developed, and what principles or foundational ethical commitments can guide their development?	More explicit incorporation of non-market values into policy regarding the powers given to global industries and the responsibilities of those same industries.	Extension of the four basic public health ethics of autonomy, beneficence, non-maleficence, and equity (social justice) to complex eco-epidemiological contexts in which global industries are important actors.

In sum, additional research in a broad range of areas is needed to improve our understanding of the ecologically-mediated population health impacts of global industries. However, since epidemiology is an applied science that aims at influencing policy to improve public health, some of the general areas and specific types of research recommended in Table 24. are more urgent than others. For example, improvements in methods to link ecological conditions with human health are needed, but in our estimation it is more important to conduct additional case studies of specific global industries. If possible, better methods and more focused searches would be employed, so that recurrent challenges and themes in ecological impacts, reflective of the actual operation of existing industries, could be identified. This would provide more credibility to proposed conceptual or theoretical models of ecological-human health relationships, by providing a richer real-world base of quantitative and qualitative data. Also, there should be no deferral of research into the relevant ethical and philosophical dimensions in this field, such as personal and community autonomy (specifically, the question of forced versus voluntarily accepted risks) and equity (specifically, the question of the distribution of ecologically-mediated health benefits and health harms or risks). Also needed is the establishment of foundational ethical principles and clear population health goals (in relation to other implicitly or explicitly stated societal goals) to guide the prioritization of research questions in this very large area of inquiry.

7.3. Benefits of a transdisciplinary approach

Epidemiological research regularly relies on theory, insights, and data from other disciplines, such as medicine and sociology, to properly frame questions, collect and analyze data, and interpret results. However, it remains unclear in many instances to what extent epidemiological research intersects or complements the research being conducted in these other disciplines. Multiple disciplines, each offering a unique perspective on a common problem and attempting to borrow relevant theoretical and methodological material from one another, constitutes the multi- or the inter-disciplinary enterprise. This study recognized numerous areas where the expertise of other disciplines was needed, and where multi- or inter-disciplinary modes of research could be illuminative; some of these areas of research are noted in Table 24.

Epidemiology, as an applied science in the service of public health from the community to the global, must have before it the goal of improving population health in the world's poorer countries, protecting historical population health gains in the world's richer countries, and striving for an equitable distribution of the resources dedicated to research that has these goals in mind—especially when the distribution of those resources is grossly inequitable.

Eco-epidemiology is primarily concerned with the relationship between multi-scale ecological change and population health. It emphasizes the ecological foundations of public health that operate both directly, and indirectly through human economies, to enable and sustain population health gains. In terms of the distribution of research resources, and indeed in terms of the distribution of all types of resources that can be put to service in the interest of global public health, eco-epidemiology necessarily must be concerned with situations where inequities in resource distribution are contributing to the destruction of the ecological foundations of human health. Policy-relevant resolution of the concerns explored in the present investigation requires something more than the varied but still largely independent contributions of epidemiological sub-disciplines or of academic disciplines generally; transdisciplinary approaches are required for dealing positively with issues involving globalizing processes driven by individual and collective human activity. Given this need, it is still critical that research and action also be oriented to local and regional contexts, if only for the reason that planet-wide ecological changes are nevertheless felt through impacts to the more immediate ecological and weather conditions of particular communities.

"Transdisciplinary" approaches to human health have been defined as approaches that integrate the natural, social, and health sciences in a humanities context, and in so doing transcend each of their traditional boundaries (Soskolne, 2003). Such approaches hold promise in a research context where, as McMichael (2006) stresses, health researchers have been unaware of, or reluctant to engage in, questions of how current and future trends in ecological conditions will impact human health.

Integration of knowledge is the key to transdisciplinarity. The results of an eco-epidemiological study need to be seen for what they mean to sociology, and the meaning of the sociological interpretation needs to be appropriated into the context of the humanities. There is no correct disciplinary starting point, although clear problem definition can help frame the contributions of each discipline. In our study, it was misleading and inefficient to generate a complex research proposal in the form of a causal web (Figure 13.) without more substantial prior consultation with expertise in several of the disciplines relevant to the relationships postulated in the hypothesis. These disciplines included geography, sociology, economics, marine biology and ecology, and political science. In light of the types of questions asked and the purposes of transdisciplinary research in the ecology-human health field, several issues of ethics are especially relevant.

7.4. Ethics

This study cannot adequately explore the question of ethics in the present field of inquiry. This subsection will touch only on the issue of distributional ethics related to population health risks and benefits associated with ecological change.

Equity in the distribution of the risks associated with improving population health, and the population health benefits from taking those risks, is a long-standing but often neglected concern in the field of epidemiology. In the USA, for example, a "10/90" split has resulted in funds allocation for global health research: only 10% of the resources are devoted to addressing problems that account for 90% of the global disease burden (Global Forum for Health Research, 2004). Similarly, 80% of Earth's resources are consumed by 20% of the population, and in many individual countries, the inequality in the distribution of monetary wealth is even more dramatic (World Bank, 2006). We have also noted that while, in the aggregate, humanity's overshoot of Earth's bioproductive capacity is at least 20%, demands placed on the biosphere by the wealthiest nations—those with the largest ecological footprints—are so great that several more Earths worth of productive ecosystems would be required to sustain our current global population in the lifestyle of those nations.

The GFASI demands resources from many ecosystems on the planet. Consumption of the GFASI's product, farmed Atlantic salmon, occurs primarily in the wealthiest nations of the world, though more complete geographical and socio-economic strata surveys of the market need to be conducted to more accurately determine this distribution.

There are individual health benefits to eating salmon, including farmed Atlantic salmon, and some research suggests that the lower rates of risk factors for cardiovascular disease, found in persons adopting a "Mediterranean" diet (low-fat, nutrient dense proteins such as fish, unsaturated oils, and plenty of fruits and vegetables) can be attributed in part to the reduced amount of fatty animal products in this regime (Chrysohoou et al, 2004). It was beyond the scope of the current investigation to attempt to quantify the population health benefits of expanding the consumption of salmon or farmed Atlantic salmon in general; however, these benefits are some of those which need to be considered when the distribution of the full slate of benefits and risks from the GFASI is examined. The information that price and other market features provide cannot currently be used to value the population health benefits associated with the consumption of farmed Atlantic salmon, because population health benefits which are not directly pursued through explicit public health interventions are generally positive externalities and thus unaccounted for by the responsible firms. The population health costs of the mal-distribution of consumer goods are also not incorporated into price; thus, the price of farmed Atlantic salmon does not reflect the cost to society that may occur if the consumption of farmed Atlantic salmon occurs disproportionately in the wealthiest nations, and/or, within the wealthiest nations, among the wealthiest citizens of those nations.

The consumption of farmed Atlantic salmon is a voluntary choice for the informed consumer who has the financial means to make the choice. If there is a measurable health benefit to the entire population from consuming more farmed Atlantic salmon (perhaps in combination with a reduction in the consumption of less nutritious foods), then the question of measurable health risks also becomes relevant. Are there health risks borne by certain individuals or populations in order to provide the population health benefits realized by the consumers of farmed Atlantic salmon? Eco-epidemiological principles (see Table 1.) direct the researcher to look not just at the immediate risks associated with farmed Atlantic salmon production, such as occupational risks to workers at grow-out sites, but at the risks to human health from regional/local and global scale changes in ecological integrity to which the industry contributes and in which, by virtue of their acts of consumption, consumers also are implicated. The current logic of the market requires only that there is a buyer for a product, and that the production and consumption of that product is legal under current arrangements; there is nothing that requires producers to provide substantial pre-production evidence of the range and likelihood of population health impacts (especially those which might be associated with global scale drivers of ecological change) with the production of their product, its use, or its end-of-life management. Without this kind of information, we cannot assess adequately the distributional features of the population health risks and benefits connected to the production of specific internationally traded goods and services. Thus, much more comprehensive accounting is required of industry and of the regulators of industry in order to answer important questions of distributive justice.

The question of the allocation of fish for various end-uses is also partly a question of ethics. Some international covenants and guidelines already raise questions about the diversion of fish from direct human consumption to exported fishmeal and fish oil products which are used for less energetically efficient subsequent production of other fish, animal, and vegetable products. For example, the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) asserts that, "States should encourage the use of fish for human consumption and promote consumption of fish whenever appropriate." While the precise nature of the pressure that the GFASI exerts on the Peruvian anchovy fishery, and indeed on all the reduction fisheries in Peru, could not be determined, trade data still show that millions of tonnes of high-quality protein are exported from Peru each year, and that a large portion of this protein is used to feed livestock and fish (such as farmed Atlantic salmon) for consumption in countries where the population health problems related to nutrition are largely problems of over-nutrition. While these problems are present for some subpopulations in Peru, under-nutrition reflected in underweight and stunting rates in children remains a serious population health problem. If consumption of anchovies and other "reduction" fish available domestically was strategically increased, it is at least conceivable that many cases of disorders of under-nutrition could be eliminated. Thus, the market forces that continue to drive the export of fishmeal and fish oil from Peru need to be evaluated against other means for improving nutrition-related population health in Peru, such as employing governance instruments to make more of the nutritious food produced domestically available for domestic consumption.

It is not just the capture fisheries and the demands of global aquaculture that drive change in marine ecosystems and threaten prospects for future flows of goods and services from these ecosystems. For example, human activities that accelerate global warming also contribute; through direct and indirect modes of action, global warming changes the habitability of the oceans for myriad species. Over some time scales, it may be correct to say that our energy-intensive agriculture, or our growing use of motor vehicles worldwide, will have contributed more substantially to changes in the productivity of Earth's marine ecosystems than fishing itself. This does not excuse the part that unsustainable fishing plays in the loss of oceanic ecological integrity, but points to the need for comprehensive reform.

In sum, relevant questions of ethics in research dealing with the ecologically-mediated population health consequences of global-scale industrial activity include: the question of which research questions, or more specifically the investigation of which consequences of industrial activity, take highest priority; questions of the distribution of the risks and benefits of industrial activity among populations, including those risks and benefits associated with ecological changes that are commonly externalized and thus not accounted for; questions of the domestic health opportunity costs of exporting nutritious food in return for money which may be inequitably distributed in the population; and questions of the relative as well as absolute contributions to ecologically-mediated health risks generated by global industrial activity. Though not discussed here, the ethical concern of autonomy is also relevant because of the expected involuntary nature of many exposures. A useful illustration of this lack of consent is evident in the situation where ecological impacts caused by today's activities will cause population health impacts to future generations.

7.5. Other approaches to research in this field

This study raised doubts about the value of applying traditional epidemiological approaches, better suited to analyzing the relationship between variables when multiple exposures and multiple effects are not present (or of interest), to questions involving massive, unprecedented exposures such as global oceanic ecosystem change or climate change driven by the contributions of multiple production and consumption activities acting synergistically. It also revealed some of the challenges in attempting to construct an assessment tool (the accounting framework) that would require unrealistic levels of certainty about eco-health events and their specific attribution (i.e., to a particular global industry) in order to be useful. What then are some of the ways in which systemic questions about the impacts of consumption on ecological harm, and, via ecological harm, on human population health, might productively be investigated?

The importance of transdisciplinary approaches to these questions has already been emphasized. Descriptive case studies of particular global industries (in a more explicitly transdisciplinary context) may still be useful as initial ground-breaking exercises and for identifying important ecological impacts that require further investigation, and in fact such studies are emphasized as a first step in the accounting framework. A priority emphasis on case studies of industries involved in the direct transfer from the global South to the global North of ecological capital (e.g., arable land), which could be (or was previously) used for food production to support regional/local populations in the exporting regions, could be useful for showing where marginal or even undetectable benefits to population health in the importing countries are matched with negative ecologically-mediated health impacts in the exporting countries.

Other methods for understanding multi-variable systems may be useful. For example, techniques of dealing with measurement error, which is commonplace in complex systems with many novel parameters, are provided by graphical modeling (GM) and structural equation modeling (SEM) techniques. The proposed causal web shown in Figure 13. might be adapted into a GM or SEM, although this would require a better initial conceptual understanding of the relationships between the variables, as well as high quality data and/or values for the covariances between all the variables. A GM or SEM could be a more efficient and more conclusive means of rejecting inaccurate formulations of the operative causal web, and for directing further research towards especially important or conceptually problematic variables.

Multilevel or hierarchical modeling techniques recognize that individual and group-level exposures often combine to create population health outcomes. This insight, and the methods developed to incorporate the insight into statistical modeling, may be useful in research that aims at clarifying the ways in which ecological impacts ultimately affect population health. One of the concerns that reappeared consistently in this study was the differential impact that changes in health-related quantities measured grossly at the national scale (such as the national supply of fish), would have on subpopulations within a country.

Some problems with the accounting framework as it was developed in this study were noted in Chapter 6. The basic need to assess and, if possible, to predict the impact of global industrial activity on population health via ecological change remains a priority if we are to make collective behavioural changes that reflect the values we place on current and future human health. As a tool for guiding the assessment of ecologically-mediated population health impacts of extant industries, the accounting framework as developed in this study has questionable utility mainly because the administrative burden of collecting the necessary data is so great.

7.6. Data and information needs

Table 25. below identifies salient data and information gaps associated with the case study of the GAFSI and more specifically with the proposed causal web shown in Figure 13.

Table 25. Data and information needs

Data and information needs for better understanding ecologically-mediated population health impacts of the GFASI
1. Precise information on ecosystem origin of fish used in all fishmeal and fish oil inputs in the industry
2. Precise information on species composition of all fishmeal and fish oil used by the industry
3. Features of the relationship between the international demand for fishmeal and fish oil by the GFASI and the response of the reduction fisheries (in terms of catch effort)
4.Reliable trend data on volume and geographic distribution of demand for farmed Atlantic salmon
5. Improved data on features of ecosystem health in all ecosystems providing fish consumed by the GFASI in the form of fishmeal and fish oil
6. Improved data on the types and distribution of impacts of the GFASI on terrestrial ecosystems, via demand for agricultural products (e.g., soy) and through contribution to climate change processes
Data and information needs for improved evaluation of the accuracy of the proposed causal web in Figure 13.
1. More accurate data on actual consumer demand for "farmed Atlantic salmon" (versus salmon in general)
2. Accurate information on changes to the Peruvian anchovy fishery which are attributable to demand for Peruvian fishmeal and fish oil by the GFASI
3. Trend data on direct human consumption rates of anchovies in Peru
4. Accurate information on changes to fishing effort and to domestic fish supplies (in Peru) as a result of policy changes at sub national, national, and international levels, including trade regulations and devaluations of the Peruvian sole to encourage export production
5. More accurate historical data on ecosystem impacts of toxic effluent and other emissions from fishmeal and fish oil processing plants, especially with respect to the health of populations of marine food fish and reduction fish in Peruvian waters
6. Information on the correspondence between total domestic supply of fish in Peru and actual fish consumption (as indicated by survey data at the household level)
7. Information on the role that fish consumption has played historically in the nutritional status of at-risk subpopulations in Peru

Chapter 8. Conclusions

8.1. Outline of this chapter

This chapter provides concluding remarks on the value of the present research, features of the GFASI which may bear on ecologically-mediated human health impacts in the future, and an advocacy role for epidemiology in policy change.

8.2. Conclusions

The value of our exploratory case study, and the attempt to develop an accounting framework for assessing the ecologically-mediated population health impacts of global industries, may exist mainly in its extension of thinking about population health benefits and harms which are not realized for generations. Human activities that contribute to climate change, or to reductions in EI that make human settlements more vulnerable to stress, are activities that necessitate consideration of population health impacts in the relatively distant future. When human economic activities result in changes to ecosystems or even global climatological processes, and not just to the generation of exposures in the present tense, health impacts on future generations become especially relevant.

Further, this concern has to do not simply with known exposures occurring in future periods, but with unprecedented changes to the productivity and integrity of Earth's ecosystems. Together these qualities are foundational to the provision of unmediated health-promoting goods and services to humans, such as clean air and biological control of disease vectors, and to the flourishing of human economies that transform raw materials into usable products.

This study suggests that important questions about the population health of our grandchildren cannot be addressed by looking only at projections of how, for example, increasing rates of obesity will affect adult health, or how monetary wealth and its distribution in the world's economies will impact life expectancy and infant mortality. Learning to know and respect the multiple relationships that exist between ecosystem processes at all scales and sustainable population health in human communities is critical.

In this study we were able only to raise and partially clarify questions about the ecologically-mediated human health impacts associated with one growing human enterprise, the global farmed Atlantic salmon industry.

Rather than define a precise thread from consumption activity (e.g., buying and eating a serving of farmed Atlantic salmon) to a small number of specific ecologically-mediated population health outcomes in a distant country, our case study was only able to affirm that we are creating unprecedented pressures in a system of unknown ecological tipping points. Also, we were able to state that some of these pressures, to which the GFASI contributes, are exerted far from the focus of the attention of the consuming public. In the case of the GFASI, that public focus has tended to be on the regional ecological integrity of the farmed Atlantic salmon grow-out sites, such as those in the coastal marine environments of British Columbia, Canada. This is only part of the picture, and it is unclear whether it is the most important part of the GFASI's total ecologically-mediated impact on human population health.

Technological improvements leading to increased energy efficiency in the GFASI could reduce the aggregate ecological footprint of the industry. Substantial and simultaneous changes in the three proportions or efficiencies that together define the technological features of the biological demand of the GFASI (the conversion of fish into fishmeal and fish oil, the fishmeal and fish oil content of farmed Atlantic salmon feed, and the efficiency with which feed is converted into farmed Atlantic salmon biomass), have the potential to reduce the industry's impact considerably. However, progress in these areas is ineffective in reducing impact so long as the consumer demand for farmed Atlantic salmon continues to grow. Even if demand for farmed Atlantic salmon slows or declines, the growing consumer demand for other species of newly farmed finfish species such as cod, halibut and tuna, all of which require high inputs of wild fish in their diets, will create mounting pressures on wild fish populations for feedstock (Naylor and Burke, 2005).

As evidence grows of ecosystem decline in the major marine ecosystems currently supporting the wild fish that are reduced to the fishmeal and fish oil consumed by the GFASI, the industry may shift demand for wild fish to other more intact marine ecosystems. This practice may temporarily limit shocks from underlying ecosystem degradation in the original regional/local fisheries that were capturing these wild fish, but concurrently contribute to a global reduction in the bioproductivity of the oceans, leading to large-scale ecosystem re-equilibration and the potentially irretrievable loss of a highly important food source for human beings. Such a catastrophic situation might be avoided if GFASI countries were more regionally self-sufficient in terms of the biological inputs (i.e., wild fish embodied in fishmeal and fish oil, but also land-derived products) used in their grow-out operations.

In terms of developing public health policy to reduce risks associated with ecological change, the global reach of industrial activity creates serious challenges. The incongruity between ecosystem or eco-region boundaries and political boundaries, and the lack of universally accepted international legal and decision-making structures for dealing with multi-scale health risks caused by human-induced ecological change, are two such challenges. Scientific advances that improve our understanding of ecology-human health links at multiple temporal and spatial scales must be complemented by changes in political processes that enable the translation of those understandings into effective action.

In cases where ecologically-mediated health impacts have become inevitable (such as those which will be associated with climate-changing, and thus ecosystem-changing, anthropogenic greenhouse gas emissions), eco-epidemiologists have a role in communicating risks to vulnerable communities and advocating for the deployment of resources needed for scale-appropriate secondary prevention activities. Ultimately, however, epidemiologists working in this field need to be able to challenge society to take preventive action by adopting those measures which will accomplish the central objective of reducing the burden of disease associated with ecological impacts caused by our industrial activity. Similar to the range of activities outlined for policy-makers in section 5.4, this could mean urging the permission, qualification, or prohibition of certain industrial activities; advocating for the screening of proposed activities for ecological impacts known or suspected to have negative human health consequences; urging consumers to curtail consumption of certain products in the marketplace; lobbying governments to facilitate or restrict trade with different international trading partners; and shaping policy at all levels of government that defines access to, and responsibility for impacts on the flows of ecosystem goods and services and the foundational ecological stocks that provide these goods and services.

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Glossary of Terms

Autonomy: Literally, "self ruling." Implies intentionality and freedom from coercion (Weed and McKeown, 2001). In this study, autonomy mainly refers to the power of communities to accept or reject health risks or benefits associated with ecological changes caused by industrial activity.

Biosphere: The outer "layer" of Earth that contains all the biotic and abiotic components and processes that support life; includes water, land, and air.

Buffer: A variable or constant that acts to defer or displace a consequence; in this study, the consequences in question are for the most part ecological, health-related, or both.

Business-as-usual (BAU): The existing or *status quo* way of doing things. In this study, BAU refers to corporate or industrial practices vis-à-vis ecological impacts.

Confound: In verb form, to confound means to obscure the true relationship between two variables by the operation of a third variable that is both a cause of the outcome and associated with the exposure.

Eco-health: Referring to research or concepts in that field of inquiry defined by a focus on the relationships between ecological conditions and human health.

Ecological capital: As used in this study, a term synonymous with natural capital (see below).

Ecological flows: Goods or services, produced regularly or occasionally through the life processes of an ecosystem, which can be used by inhabitants of the producing ecosystem or of another ecosystem as fuel, fibre, food, construction materials, or for non-material purposes.

Ecological Footprint (EF): The area of land and water, based on the world-average productivity of each, required to support the material, energy, and waste assimilation demands of a defined unit such as a city, country, or individual.

Ecological Footprint Analysis (EFA): The process of determining Ecological Footprints.

Ecological health: General term for the vitality and resilience of an ecosystem.

Ecological integrity: The capacity of an ecosystem to continue to provide its characteristic flow of goods and services when disturbed by external stressors (such as the influx of pollutants from industry, global warming, or resource extraction activities).

Ecological stocks: Components of ecosystems that regularly or irregularly produce

Ecologically-mediated: With respect to an impact or outcome, one that is caused wholly or in part by a normal ecosystem process or by a change in an ecosystem component induced by a stressor.

Ecology: The study of ecosystems.

Ecosphere: Synonymous with biosphere (see above) for the purposes of this study, but used to emphasize that the biosphere consists of multiple interrelated ecosystems.

Ecosystem: The collection of biotic and abiotic components and processes that comprise and govern the behaviour of some defined subset of the biosphere (Wikipedia, 2007). It should be noted that there are no solid objective rules for determining the boundaries of individual ecosystems; typically, if an ecosystem if being researched, the researcher will provide a working definition of the limits of that ecosystem. In some cases the boundaries are relatively clear (e.g., the shoreline of a pond).

Efficiency: The amount of energy and material required to produce a specific quantity of a good or service.

El Niño/ENSO: El Niño is the warm phase of the total Southern Oscillation (SO) phenomenon, which has a 3-7 cycle. In a Southern Oscillation cycle, there may be also be a cold phase, termed La Nina, or either the cold or warm phase may be substantially absent. Thus, while it is often said that one El Niño event is expected approximately every 3-7 years, there is no guarantee that one will occur at least every seven years, and it is also possible to have more than one El Niño event in a seven year period. In this study, “El Niño” is often alone, with the assumption that it is part of the SO phenomenon.

Equity: Fairness in the distribution of goods, services, or risks and benefits. Equity in this study refers mainly to the understanding of distributive justice in a public health context: that manageable health risks and benefits, in particular those associated with ecological conditions, should be fairly distributed in society.

Health: Numerous definitions exist for “health,” and the concept is an evolving one. In this study, health means both the absence of disease and the presence of positive qualities such as mental, emotional, and social well-being. The meaning of health as a state of input/output balance or equilibrium, such that the organism is optimally placed to grow and develop, also is relevant.

Human health: The health (see above) of human beings.

Humboldt Current upwelling ecosystem (HCUE): The large and biologically productive marine ecosystem off the coast of western South America; one of 12 such marine ecosystems defined globally.

Mitigate: Decrease the severity of an impact or consequence.

Natural capital: The ecological stocks (e.g., forests, nutrient cycles) and ecological flows of materials (e.g., catchable fish, fruit) on Earth.

Population health: The health (see above) of a defined collective of persons, in contrast to individual health; population health is typically indicated by relevant rates of disease in the population of interest as compared to a standard or goal, or by broad indicators of health (e.g., life expectancy, social cohesion).

Southern Oscillation (SO): The entire thermo-climatic ocean warming and cooling cycle in the southern Pacific ocean that can include the events known widely at El Niño (warm phase) and La Nina (cold phase).

Sustainability: A state in which the total, ongoing impact of economic activity (i.e., the production, distribution, consumption, and end-of-life management of goods and services) in a society does not threaten or destroy either the regenerative capacity of the ecosystems upon which the society depends or the social capacity of the society to effectively adapt to internal and external stressors in the long-term. In practice, sustainability is extremely difficult to define.

Appendix 1. Simple description of Ecological Footprint Analysis

To calculate the EF, consumption of resources for a defined period is divided into five categories: food, housing, transport, consumer goods, and services (such as the assimilation of carbon emitted through fossil fuel consumption). These resources are then linked to their particular provisioning ecological resource bases, defined as several different types of land and water areas (e.g., cropland, managed forest). For example, a country's annual consumption of wheat would have a footprint corresponding to a certain number of hectares of cropland, based on the world-average productivity of that cropland. These statistical hectares are termed "global hectares," and are the units in which EF is expressed. The total EF for the consuming unit is obtained by summing all of the land and water areas—again, based on world-average productivities for these types of land and water areas—required to support the amounts of goods and services consumed in the various consumption categories noted above. If the consuming unit is a nation or other collection of individuals, a per capita EF can be calculated by dividing the total EF by the population. Data needed for determining the consumption levels of the analyzed unit, and the world-average productivity of the different land and water types, are typically obtained from a variety of sources. These include production and trade accounts; state of the environment reports; and agricultural, fuel use, and emissions statistics (Lenzen and Murray, 2003).

Appendix 2. *Per capita*, per day fish protein consumption in grams for Peru and selected countries (2004)

All data are from FAO (2006)[1].

(2004)	Cephalopods	Crustaceans	Demersal fish	Freshwater and diadromous fish	Marine fish, other	Mollusks	Pelagic fish	TO-TAL
Peru	0.8 (g)	0.0	0.7	0.4	0.9	0.1	3.10	**6.0**
Brazil	0.0	0.1	0.4	0.7	0.3	0.0	0.2	1.7
Chile	0.1	0.0	0.9	0.1	0.1	0.2	1.9	3.3
Colombia	0.3	0.0	0.0	0.6	0.3	0.0	0.5	1.4
Venezuela	0.3	0.1	0.9	0.5	0.3	0.1	2.8	4.9
Canada	0.5	0.7	1.1	1.2	0.5	0.3	2.10	5.9
USA	0.1	1.2	1.5	0.8	0.1	0.2	0.8	4.7

[1] Data are based on production, export, and import statistics, and thus serve as a proxy for actual protein consumption.